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December 20, 2013

Stephanie Vaughn
U.S. Environmental Protection Agency, Region II
290 Broadway
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Via Electronic Mail

Re: ***Preliminary Draft Interim Conceptual Site Model Submission – Preliminary Draft - Lower Passaic River Study Area (LPRSA) Administrative Agreement and Order on Consent for Remedial Investigation/Feasibility Study (RI/FS) - CERCLA Docket No. 02-2007-2009***

Dear Ms. Vaughn:

The Lower Passaic River Study Area Cooperating Parties Group (CPG) is submitting a preliminary draft of the LPRSA Interim Conceptual Site Model (Interim CSM) for the purposes of discussion and collaboration between USEPA and the CPG on the LPRSA RI/FS. Please note this information is being provided for discussion purposes only between USEPA Region 2 and the CPG.

This submission does not constitute a deliverable as defined by the May 2007 RI/FS Settlement Agreement.

The discussions presented in the Interim CSM do not include a full treatment and the analyses of the following:

- High Volume Chemical Water Column data
- Upper Passaic River Background and Reference data
- SSP 2 Low Resolution Coring data

The CPG is providing this information with the understanding that it will not be distributed outside of the USEPA and its technical contractors prior to discussions between USEPA and the CPG.

The CPG requests the opportunity to meet and discuss with USEPA and its technical contractors the Interim CSM during the week of January 20, 2014.

In addition, the CPG requests the USEPA's most recent LPR CSM document; this would make the meeting would be more productive and collaborative if USEPA Region 2 provided the CPG with the current USEPA LPR CSM for discussion purposes in early January 2014.

The references listed in Section 7 of the Interim CSM will be forwarded to USEPA under separate cover. The underlying data that supports the Interim CSM has been previously posted to USEPA's LPR SharePoint.

Please contact Bill Potter or me to discuss.

Very truly yours,

de maximis, inc.

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PAPER

LOWER PASSAIC RIVER STUDY AREA REMEDIAL INVESTIGATION/FEASIBILITY STUDY

INTERIM CONCEPTUAL SITE MODEL

Preliminary Draft – For Discussion Only

Prepared for

Lower Passaic River Cooperating Parties Group

December 2013

ACKNOWLEDGEMENTS

This interim Conceptual Site Model was prepared on behalf of the Lower Passaic River Cooperating Parties Group and contains contributions from several companies, including the following:

- AECOM, Chelmsford, Massachusetts
- Anchor QEA, LLC, Montvale, New Jersey, and Boston, Massachusetts
- de maximis, inc., Clinton, New Jersey
- Integral Consulting, Lexington, Massachusetts
- mab environmental, LLC, Hilton Head Island, South Carolina
- Windward Environmental, LLC, Seattle, Washington

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LIST OF ACRONYMS AND ABBREVIATIONS

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
ADCP	Acoustic Doppler Current Profiler
BERA	Baseline Ecological Risk Assessment
CAS	Creel/Angler Survey
cfs	cubic feet per second
cm	centimeter
cm/yr	centimeters per year
CPG	Cooperating Parties Group
Cs-137	cesium-137
CSM	Conceptual Site Model
CSO	combined sewer overflow
CWA	Clean Water Act
CWCM	chemical water column monitoring
cy	cubic yards
DDT	dichlorodiphenyltrichloroethane
DDx	DDT and its related products
DO	dissolved oxygen
ETM	estuarine turbidity maximum
FS	Feasibility Study
HHRA	Human Health Risk Assessment
HMW PAH	high molecular weight polycyclic aromatic hydrocarbon
HOT	head of tide
HQI	HydroQual, Inc.
kg	kilograms
LMW PAH	low molecular weight polycyclic aromatic hydrocarbon
LPR	Lower Passaic River
LPRSA	Lower Passaic River Study Area

LRC	low resolution coring
m	meter
mg/L	milligrams per liter
MLW	mean low water
MPI	Malcolm Pirnie Inc.
NGVD29	National Geodetic Vertical Datum 1929
NJ	New Jersey
NJDEP	New Jersey Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NY	New York
OC	organic carbon
OU	Operable Unit
PAH	polycyclic aromatic hydrocarbon
Pb-210	Lead-210
PCB	polychlorinated biphenyl
PFD	Problem Formulation document
ppt	parts per thousand
PWCM	Physical Water Column Monitoring
RARC	Risk Analysis and Risk Characterization
RI	Remedial Investigation
RM	river mile
SEI	Sea Engineering Inc.
SLERA	Screening Level Ecological Risk Assessment
SSC	suspended solids concentration
SSP	Supplemental Sampling Program
SSS	side scan sonar
SWO	stormwater outfall
TEQ	toxic equivalents quotient

TMDL	total maximum daily load
TOC	total organic carbon
TSI	Tierra Solutions Inc.
TSS	total suspended solids
UPR	Upper Passaic River
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

1 CONCEPTUAL SITE MODEL OVERVIEW AND COMPONENTS

This document presents an interim Conceptual Site Model (CSM) for the Lower Passaic River Study Area (LPRSA). The LPRSA is an Operable Unit (OU) of the Diamond Alkali Superfund Site in Newark, New Jersey (NJ), and includes the 17.4-mile Lower Passaic River (LPR) and its watershed (see Figure 1-1). This interim CSM describes the current understanding of the physical, chemical, and biological processes that control the fate and transport of contaminants in the system and their transfer from sediments and water to potential human and/or ecological receptors. It is based on the knowledge gained from review of both past studies and the extensive data collected as part of the ongoing LPRSA Remedial Investigation (RI)/Feasibility Study (FS). The considered data include: 1) physical, chemical, and radiochemical measurements on sediment samples; 2) bathymetric surveys; 3) physical and chemical water column monitoring (CWCM); and 4) benthic and fish tissue analysis. Data have been collected throughout the LPRSA, and an intensive data collection was also performed as part of a focused program at LPR river mile (RM) 10.9, the location of a 2013 removal action. The CSM is continually refined as additional information is obtained. It can help identify remedial strategies, including source control and natural recovery, to achieve significant and meaningful risk reductions.

The LPR is a partially mixed estuary. It is bounded upstream by Dundee Dam to the north and downstream by Newark Bay to the south. It is subject to freshwater inputs from the Upper Passaic River (UPR) watershed (above Dundee Dam), three major tributaries (Second River, Third River, and Saddle River), and a limited number of minor tributaries; direct discharges from stormwater outfalls (SWOs) and combined sewer overflows (CSOs); and tidal inflows from Newark Bay. Sediment chemistry data indicate the presence of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) and other dioxin and furan congeners; polychlorinated biphenyls (PCBs); polycyclic aromatic hydrocarbons (PAHs; separated into low and high molecular weight subsets [LMW and HMW, respectively]); the pesticides dichlorodiphenyltrichloroethane (DDT) and its related products (collectively DDx), dieldrin and total chlordane; the metals mercury, copper, and lead; and several other contaminants. The LPR's distinguishing factor is its elevated levels of 2,3,7,8-TCDD in sediments (see Appendix B for additional details), which is atypical of other urban river sites. The analyses herein are focused on these contaminants, based on their potential to contribute to ecological and human health risks in the LPRSA.

Various investigators have noted that the LPR has been an effective sediment and contaminant trap for more than 60 years (Chant et al. 2010; Bopp et al. 1991; Geyer 1993; Dyer 1988). It has been subjected to a broad range of contaminant loadings from sources discharging directly into it, entering via tributaries, or across upstream or downstream boundaries. Dated sediment cores suggest that peak loading for most contaminants occurred in the 1950s to 1960s, before the passing of the 1972 Federal Water Pollution Act amendments (see Section 3.2 for associated analyses).

Comprehensive analyses of sediment and water chemistry data, physical and chemical fate and transport processes, hydrology, dredging history, anthropogenic shoreline and channel alterations, and geomorphology have yielded a thorough understanding of the contaminant patterns in the sediment, water column, and biota and the stability of the sediment deposits. This understanding provides a basis for designing remedies to efficiently reduce potential human and ecological risks, and accelerate overall recovery. The recovery for a number of contaminants is impacted by ongoing sources (see Section 3.3); a remedy that addresses components beyond the LPR (e.g., sediments from Newark Bay or in urban runoff) is required to prevent re-contamination and maintain long-term risk reduction goals to achieve a sustainable solution for the system.

Section 2 of this document briefly introduces the LPR and discusses its current state in the context of its urban nature and the historical development that occurred in its watershed. Section 3 discusses the nature and extent of contamination and the impact of ongoing external sources on contaminant levels. Section 4 describes the ecological and human health risk drivers, receptors, and pathways. Section 5 discusses the hydrodynamics, sediment dynamics, contaminant fate and transport, and natural recovery of the system. Finally, Section 6 ties the various analyses together to suggest and evaluate implications for remedial design.

2 RIVER CHARACTERISTICS AND SETTING

2.1 Overview of Study Area

- The LPR is characterized by USEPA as having three distinct regimes:
  - Freshwater section
  - Transitional section
  - Brackish section
- The major freshwater input to the LPR is from above Dundee Dam.
- The salt front typically resides within the lower 10 miles of the river and can extend beyond RM 14 during extreme low flows.
- Heavy urbanization and industrialization has significantly altered the LPR watershed and shoreline, and resulted in a broad range of contaminant loadings from a multitude of sources.
- Urbanization has severely degraded habitats, which adversely impacts the benthic community.
- The loss of habitat and the continuous urban runoff have introduced non-chemical stressors to the ecosystem.
- Extensive historical dredging has made the river an effective trap of both solids and contaminants.

The LPR is the 17.4-mile, tidally influenced portion of the Passaic River located in northeastern NJ. It is one of the integral parts of the Greater Newark Bay Complex, along with Newark Bay, Hackensack River, Arthur Kill, and Kill Van Kull (see Figure 2-1). These water bodies are hydraulically connected through freshwater flows from the rivers to the ocean and by tidal flows that move water both inland and toward the ocean. The tidal flows also connect the Greater Newark Bay Complex to New York (NY) Harbor and Raritan Bay (also referred to as the NY/NJ Harbor Estuary or the Hudson-Raritan Estuary).

The LPR extends from Dundee Dam (RM 17.4) to Newark Bay (RM 0; see Figure 2-2). It receives freshwater from the UPR at Dundee Dam, three tributaries (Saddle River, Third River, and Second River), and to a lesser extent, smaller tributaries; direct discharges from CSOs, SWOs, permitted municipal and industrial discharges; and direct runoff. Groundwater contribution to the LPR is considered small relative to the freshwater flow that enters the LPR from upstream during average flow conditions (Malcolm Pirnie Inc. [MPI] 2007) but could potentially influence local sediment quality.

The LPR is a partially mixed estuary with circulation and salinity patterns that are controlled mainly by a dynamic hydraulic balance between the upstream freshwater flow and the downstream brackish tidal inflow from Newark Bay. These flows and their interactions have resulted in the U.S. Environmental Protection Agency (USEPA) classifying the LPR into the following three major sections (MPI 2007; Sea Engineering Inc. [SEI] and HydroQual Inc. [HQI] 2011):

1. RM 17.4 to RM 10—Freshwater River Section (River Dominant)
2. RM 10 to RM 6—Transitional River Section (Mixed)
3. RM 6 to RM 0—Brackish River Section (Estuary Dominant)

These designations are qualitative—in reality, the location of the interface between fresh and saline waters (also referred to as the "salt front") is strongly influenced by the balance between freshwater and tidal flows, as well as the system geometry. The salt front typically resides within the lower 10 miles and moves several miles during each tidal cycle (MPI 2007; Cañizares et al. 2009; see Section 5.1), and can extend beyond RM 14 under extreme low flow conditions (SEI and HQI 2011). The location of the salt front typically coincides with the location of the estuarine turbidity maximum (ETM), that is, the region of an estuary with maximum turbidity (Dyer 1995; Chant et al. 2010; see Section 5.1 and Section 5.2).

As with most rivers, the LPR increases in flow and cross-sectional area moving from upstream to downstream. Flow velocities tend to be higher in the narrowest and shallowest region of a river than near the mouth, resulting in increasing deposition and decreasing sediment particle sizes as the river moves downstream. Additionally, estuarine rivers like the LPR are impacted by tidal flow reversals, stratification, and a moving salt front, further intensifying silt/fine-grained sediment accumulation in their downstream ends. Moreover, estuarine dynamics tend to induce a net upstream transport of solids during low flows in the region downstream of the salt front and the ETM, which can redistribute surface sediments (see Section 5).

The Freshwater River Section (RM 17.4 to RM 10) tends to be, relative to the downstream areas, largely non-depositional and is characterized by mostly coarse-grained sediments with small, shallow pockets of silt/fine-grained sediments (see Figures 2-3a and 2-3b). It is influenced by tributary inflows from the Saddle River and Third River. The Transitional River Section (RM 10 to RM 6) is by comparison more strongly influenced by fluctuating water velocities, flow direction, and salinity levels, and is also influenced by tributary inflow from the Second River. Within this river section, sediments transition from a majority coarse-grained near the boundary with the Freshwater River Section to predominantly fines/silts (see Figures 2-3a and 2-3b). The Brackish River Section (RM 6 to RM 0) is characterized by salinity levels consistently greater than 5 parts per thousand (ppt) and significant tidal influence on flow velocity and direction. This section is primarily characterized by fines/silt, and the unmaintained navigation channel within this section has experienced significant deposition and contains deep beds of fine sediments (see Figures 2-3a and 2-3b).

The LPR is a meandering river with two sharp oxbows at RM 14 to RM 16 and another large oxbow at RM 1.5 to RM 4. The lateral shorelines of these bends are subject to higher velocities and greater erosion than the interior shorelines. Interior shorelines of bends as well as shallow, nearshore areas are subject to lower flow velocities and higher deposition rates than the main channel (see Figures 3.1 through 3.4 in CH2MHill [2013]). In some locations, such as the silt deposit at RM 10.9, the nearshore shallow sediments are subject to near zero flow velocities, and extensive mudflats have formed.

The annual average discharge at Little Falls is 1,140 cubic feet per second (cfs; 1,200 cfs at Dundee Dam, based on drainage-area proration). MPI (2007) concluded that all other inflow sources contribute less than 20 percent of the annual average freshwater inflow to the LPR. Peak daily average flows at various statistical recurrence intervals are presented in Table 2-1[1].

Data collected at the National Oceanic and Atmospheric Administration station at Bergen Point West Reach indicate that LPR tides are semi-diurnal, with a period of approximately 12.5 hours. Water levels exhibit a spring-neap period of 13.5 days. The tidal range varies between 0.9 meter (m) at neap tide and 2.2 m at spring tide (3.0 to 7.2 feet).

2.2 Urban Setting and Historical Context

The LPRSA is located within one of the major centers of the American Industrial Revolution. Early manufacturing was established near Paterson, NJ, during the post-colonial era. Beginning with cotton mills, the LPR watershed, concentrated along the river, grew to include manufactured gas plants; petroleum refineries; tanneries; ship building; smelting;

[1] This is based on records spanning from 1896 to 2012 at the U.S. Geological Survey (USGS) Little Falls gage station. The record 35,000-cfs event reported in 1903 was affected by a dam failure and, therefore, was not included in the analysis.

pharmaceutical, electronic product, dye, paint, pigment, paper, and chemical manufacturing plants; and other industrial activity (Shear et al. 1996; MPI 2007; AECOM 2011a). Major population centers such as Paterson and Newark transformed the watershed into a mix of residential, commercial, and industrial uses. Thus, as with many other urban river systems, the LPR has been subjected to a broad range of contaminant loadings from multiple sources (e.g., untreated industrial and municipal wastewater, CSOs/SWOs, direct runoff, atmospheric deposition) for a long time. Its distinguishing factor is elevated levels of 2,3,7,8-TCDD in sediments, which is atypical of other urban sites.

The LPR is one of three OUs of the Diamond Alkali Site at 80 and 120 Lister Avenue in Newark, NJ (OU-1 is 80 and 120 Lister Avenue, OU-2 is the LPR, and OU-3 is Newark Bay). Various companies at the 80 and 120 Lister Avenue facilities manufactured chemicals such as pesticides and phenoxy herbicides, including the primary components used to make the military defoliant Agent Orange. Chemical manufacturing and compounding occurred at this location from the 1940s through the 1960s (Bopp et al. 1991, 1998; Chaky 2003; Lillienfeld and Gallo 1989). The Diamond Alkali Site, also referred to as the Lister Avenue Site, was placed on the National Priorities List (NPL) in September 1984 due to 2,3,7,8-TCDD contamination detected in on-site and off-site soils and groundwater. Several investigators have since concluded that the Lister Avenue Site was the dominant 2,3,7,8-TCDD source to the LPRSA (Bopp et al. 1991, 1998; Chaky 2003; Hansen 2002), and a significant historical DDT source (Bopp et al. 1991, 2006). The Lister Avenue Site underwent several remedial actions under New Jersey Department of Environmental Protection (NJDEP) and USEPA oversight between 1984 and 2004 (USEPA 2008; Tierra Solutions Inc. [TSI] 2008). In 2012, Occidental Chemical Corporation entered into an Administrative Order on Consent with USEPA requiring the removal of 40,000 cubic yards (cy; Phase 1) of the most dioxin-contaminated sediments from the LPR in the immediate vicinity of the Lister Avenue Site (see Figure 2-4), and an additional future removal of 160,000 cy of LPR sediments from an adjacent shoreline area on either side of the Phase 1 Removal Action (Phase 2).

Dated sediment cores show that peak loading for most major contaminants, including 2,3,7,8-TCDD, occurred in the 1950s to 1960s (see Section 3.2). Discharges to the LPRSA declined following the 1972 Federal Water Pollution Control Act amendments (Clean Water Act [CWA]) and subsequent regulations but still occur. The LPR remains non-compliant with federal and state water quality criteria and standards for many contaminants and non-chemical discharges such as pathogens and nutrients from regional sources (i.e., upstream of Dundee Dam, Newark Bay, tributaries, and other direct inputs). Total maximum daily loads (TMDLs) are being developed for both nutrients and toxics (USEPA 2013).

Urbanization altered the physical characteristics of the river—most tidal marshes, wetlands, and mudflats were filled in or dredged, thus, gradually transforming the LPR into a highly channelized river, with the lower 8 miles dominated by hardened shorelines (e.g., sheetpile, riprap, wood pilings; AECOM 2011a; MPI 2007). Major historical developments include the completion of the Dundee Dam and lock system in 1858 (AECOM 2011a), the subsequent expansion of regional shipping activities to accommodate growing commercial transportation needs, and the operation of 15 bridges spanning the LPR (U.S. Army Corps of Engineers [USACE] 2010). A federal navigation channel of varying depth extending from the mouth of the river (RM 0) to the Eighth Street Bridge in Wallington, NJ (RM 15.4), was created in the late 19th century (USACE 2010). This channel had the following four distinct segments due to four different authorized depths (USACE 2010):

1. 30-foot segment (RM 0 to RM 2.6): The channel has an authorized constructed depth of 30 feet mean low water (MLW) and is 300 feet wide. The mean tidal range in this segment of the river is 5.5 feet.
2. 20-foot segment (RM 2.6 to RM 7.1): The channel has an authorized constructed depth of 20 feet MLW and is 300 feet wide. From RM 4.1 to RM 7.1, the channel had an authorized depth of 20 feet MLW and is 300 feet wide; however, the project was only constructed to 16 feet MLW.
3. 16-foot segment (RM 7.2 to RM 8.1): The channel has an authorized constructed depth of 16 feet MLW and is 200 feet wide.
4. 10-foot segment (RM 8.1 to RM 15.4): The channel has an authorized constructed depth of 10 feet MLW and is 150 feet wide.

The channel was subject to numerous deepening and maintenance dredging activities over its first 50 years of existence. No new channel construction was authorized after 1932, but the existing channel was continued to be maintained for nearly 50 years. The river was busy with traffic during the 1940s because the height of industrialization and manufacturing on the river coincided with World War II. Post-1950, most of the maintenance dredging focused primarily on the lower 2 miles of the channel. The last maintenance dredging conducted by USACE in 1983 removed more than 500,000 cy of sediments to a depth of 30 feet MLW in the lower 1.9 miles of the channel (USACE 2010).

The 2007 bathymetry and most recent dredge years of the different sections of the navigation channel are shown on Figure 2-5. The blue line represents the median dredge depth estimated visually from the bathymetry in post-dredge drawings; the solid black line represents 2007 bathymetry. Significant infilling is evident; the downstream sections often have 10 feet or more of sediment deposited over the original dredged channel. The LPR has been an efficient sediment trap, and is now approaching a dynamic equilibrium (Chant et al. 2010); that is, the channel will retain its shape subject to oscillations associated with net deposition under low to moderate river flows and net erosion under high flows.

Land use changes and physical alterations of the LPR shoreline have increased impervious surfaces and severely degraded the riverbank habitat and ecological function (Iannuzzi et al. 2002). The lower reaches (RM 1 to RM 7) are mostly developed—70 percent of this riverbank comprises concrete, metal, or wood bulkhead and/or riprap, and supports limited vegetation (Windward 2011a; see Figure 2-6). The riverbank in the upper portion of the LPR (RM 7 to RM 17.4) primarily comprises vegetation and bulkhead (see Figure 2-6). Access to the western bank is restricted due to NJ Route 21—the limited area between the roadway and the river mostly comprises sparse vegetation, steep slopes, and in places, hardened banks and road supports.

Higher frequency of flash floods, elevated nutrient levels, lower nutrient uptake, altered stream morphology, increased amounts of tolerant species, decreased amounts of sensitive species, and an overall decrease in diversity are evidence of the urban stream syndrome (Walsh et al. 2005). Other stressors, including changes in dissolved oxygen (DO), temperature, and/or turbidity also significantly impact biota within the ecosystem. The increased channelization of the river and lack of riparian and submerged vegetation offers fewer habitats for organisms and creates an unbalanced food web with an increase in invasive species (see Section 3.4).

3 ENVIRONMENTAL CONDITIONS

3.1 Contaminants

- Lister Avenue Site discharges had a widespread and dominant influence on 2,3,7,8-TCDD concentrations in the lower 12 to 14 miles of the LPR and Newark Bay.
- For many contaminants, surface sediment concentrations correlate with 2,3,7,8-TCDD concentrations. Regions with high concentrations of contaminants are typically associated with high concentrations of 2,3,7,8-TCDD. Correlations between PAHs and 2,3,7,8-TCDD are weaker but still exist.
- Contaminants other than 2,3,7,8-TCDD are impacted by upstream, downstream, and/or watershed influences.
- Large-scale concentration gradients are muted over the lower 12 miles, presumably due to tidal mixing and sediment redistribution processes.
- Concentrations of contaminants dominated by sources in the lower 12 miles or Newark Bay tend to decrease upstream of RM 12 due to the declining influence of tidally induced net upstream sediment movement.
- Concentrations of contaminants dominated by sources upstream of Newark Bay decrease into Newark Bay due to dilution with water and solids from the bay.
- The highest contaminant concentrations are typically buried at depth in the sediment bed.

Several contaminants, including 2,3,7,8-TCDD, PCBs, HMW and LMW PAHs, DDx, dieldrin, total chlordane, mercury, copper, and lead, have been identified as possible contributors to risk within the LPRSA. Non-chemical stressors such as organic matter, nutrients, and invasive species also have an adverse ecological impact on the LPR. The following sections present contaminant concentration patterns in the LPR sediments, water, and fish tissue; a discussion of the influence of various sediment and contaminant sources to the LPR; and an identification of other stressors that exist in the LPR.

3.2 Contaminant Trends

The hydrophobic nature of many contaminants causes them to sorb onto sediments. Most of the sorption occurs on the organic matter fraction of the sediments, which is typically characterized using organic carbon (OC). For this reason, spatial and temporal concentration trends are often presented on an OC-normalized basis (i.e., analyte concentration divided by the sediment OC fraction). The relationships between analyte concentration and OC content for the lower 12 miles of LPR surface sediments (0 to 6 inches) are presented on Figures 3-2a and 3-2b (the features of the box-and-whisker plot used on the figures are explained on Figure 3-1). These figures show that, in general, higher concentrations are associated with increasing sediment OC. Contaminant concentration trends in subsequent sections are thus shown on an OC-normalized basis for the post-2000 data[2]. These trends provide useful insight into the general fate and transport of contaminants, possible locations of high concentrations, and potential for recontamination post-remedy.

3.2.1 Sediments

3.2.1.1 Longitudinal Distribution

Longitudinal distributions of surficial (top 6 inches), OC-normalized sediment contaminant concentrations were examined in various ways (e.g., scatter plots, spatially binned averages, spatially binned box-and-whisker plots). In this document, sediment contaminant data are grouped spatially prior to plotting. Spatial bins were selected to provide sufficient data density in each bin, while not obscuring large-scale concentration trends. Most of the LPR (RM 14 to RM 0) is divided into 2-mile bins. RM 17.4 to RM 14 of the LPR and the UPR (RM 20 to RM 17.4) are treated as single bins. Newark Bay is divided into two equal bins at the mid-point (RM 0 to RM -2.475 and RM -2.475 to RM -4.95; referred to as the Upper Newark Bay and Lower Newark Bay, respectively). The trends exhibited by this spatial binning are consistent with those observed in scatter plots (not shown) and with other spatial binning intervals (e.g., 1 or 0.5 mile; not shown). The longitudinal distributions of OC-normalized, surface sediment contaminant concentrations—presented as box-and-whisker plots—are shown on Figures 3-3a through 3-3j. This style of presentation was selected to objectively present a summary of the data within each bin without assumptions regarding statistical distribution. Data counts for the spatial bins are posted below the respective boxes.

Surficial sediment 2,3,7,8-TCDD concentrations (see Figure 3-3a) tend to be highest in the RM 10 to RM 12 region, in part reflecting the high concentrations in the RM 10.9 mudflat[3].

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[2] Data collected prior to 2000 are confounded by various factors, including: 1) varying objectives, sampling protocols, and analytical methods for different surveys; 2) incomplete spatial coverage throughout the LPR; and 3) increased data variability. The post-2000 datasets listed in Table 3-1 were developed under a consistent set of objectives/protocols and provide complete spatial coverage throughout the LPR. To eliminate the potentially confounding influences of these earlier datasets, only the post-2000 datasets were considered in the discussion of contaminant trends.

[3] The summary statistics for the RM 10 to RM 12 bin partially reflect the 2011 AECOM/CH2MHill River Mile 10.9 Field Investigation, which delineated a distinct region of elevated concentrations in the eastern shoal.

Similar high concentrations also exist in the eastside shoal in the RM 6 to RM 8 region. In general, the concentration trends appear to reflect differences in sedimentation among locations—locations with the highest concentrations typically have low sedimentation (see Section 5.4.2). Between RM 12 and RM 14, concentrations decline by more than two orders of magnitude, consistent with the declining influence of the ETM and upstream transport from the lower river (see Sections 5.1, 5.2, and 5.3). Upstream of approximately RM 14, concentrations are typically consistent with those measured upstream of Dundee Dam. Moving downstream from the RM 6 to RM 8 bin into Newark Bay, concentrations decline by approximately an order of magnitude. The trends here reflect the upstream and downstream tidal transport patterns and along-river variations in sedimentation rate, which affect recovery (see Sections 5.3 and 5.4).

Concentrations of a number of the other contaminants correlate with 2,3,7,8-TCDD. Surficial (0 to 6 inches) sediment contaminant concentrations in the lower 12 miles of the LPR (also referred to as the Lower LPR) are plotted against the corresponding 2,3,7,8-TCDD concentration on Figures 3-4a and 3-4b. These plots indicate that regions with high concentrations of contaminants are typically associated with high concentrations of 2,3,7,8-TCDD. The relationship of PAHs to 2,3,7,8-TCDD seems weakest, suggesting a larger difference in the spatial and/or temporal characteristics of PAH sources. But even with this difference, higher 2,3,7,8-TCDD concentrations tend to be associated with higher PAH concentrations.

Despite the correlation between 2,3,7,8-TCDD and other contaminants, their large-scale longitudinal concentration patterns are somewhat different. Like 2,3,7,8-TCDD, Total PCBs show high concentrations in the RM 10.9 mudflat but do not exhibit similarly strong longitudinal trends in surficial sediment concentrations (see Figure 3-3b). Rather, Total PCB concentrations are fairly uniform throughout the lower 14 miles of the LPR and in Newark Bay. This muted pattern suggests the influence of diffuse sources, particularly downstream of the LPR and perhaps also within the LPRSA.

PAH concentrations also suggest the influence of diffuse sources external to the LPR. HMW PAH concentrations exhibit a general decline of about an order of magnitude from above Dundee Dam to the lower 12 miles of the LPR (see Figure 3-3c), suggesting that LPR sediment HMW PAH concentrations are influenced by upstream sources. LMW PAH concentrations exhibit a similar trend—concentrations are fairly uniform through the lower 12 miles—and there is a lack of decline moving upstream of RM 14, indicating possible upstream sources (see Figure 3-3d). The LMW PAH trend also suggests a potential downstream influence on LPR sediments, given the elevated concentrations in lower Newark Bay (unlike HMW PAHs).

Total DDx concentrations exhibit a spatial pattern similar to that of 2,3,7,8-TCDD but with a few notable differences (see Figure 3-3e). Concentrations decline with distance upstream of RM 12, although to a lesser extent than 2,3,7,8-TCDD, presumably reflecting historical DDT use in the upstream watershed. The decline moving downstream into Newark Bay is also less pronounced, and the elevated concentrations measured in lower Newark Bay suggest the influence of sources downstream of the LPR.

Dieldrin concentrations are relatively uniform throughout the entire LPR, suggesting a combination of upstream, downstream, and watershed influences (see Figure 3-3f). Total chlordane concentrations are also relatively uniform throughout the entire LPR but are slightly higher than those in the UPR and Newark Bay (see Figure 3-3g), suggesting a greater LPRSA watershed influence.

Mercury concentrations are highest in Upper Newark Bay and are relatively uniform in the lower 12 miles of the LPR, suggesting a downstream influence and possibly a watershed influence (see Figure 3-3h). The copper concentration trend suggests a similar downstream influence, with the highest concentrations in Newark Bay, and relatively uniform concentrations in the lower 12 miles of the LPR (see Figure 3-3i). Lead concentrations are fairly uniform throughout much of the LPR and Newark Bay, suggesting a combination of downstream and watershed sources (see Figure 3-3j).

To summarize these longitudinal trends, concentrations of most contaminants in surface sediments exhibit no consistent trends in the Lower LPR, which is consistent with the influence of tidally induced net upstream sediment movement under most conditions (see Section 5). Concentrations of most contaminants tend to decline either upstream or downstream of the Lower LPR, or not decline at all outside the Lower LPR, suggesting a combination of upstream, downstream, or watershed influences. The main exception is 2,3,7,8-TCDD, which decreases both upstream and downstream of the Lower LPR. Moreover, the magnitude of the decline of 2,3,7,8-TCDD upstream of RM 12 and across Newark Bay appears greater than that of other contaminants declining in these regions. These observations suggest that 2,3,7,8-TCDD is dominated by an internal LPR source, whereas other contaminants exhibit varying degrees of external influence. The subsequent sections discuss additional aspects of observed contaminant patterns, and their importance in understanding the system.

3.2.1.2 Vertical Distribution

Example vertical profiles of 2,3,7,8-TCDD, collected immediately adjacent to the Lister Avenue Site in January 2011, show peak concentrations that are 5.2 to 7.5 feet (160 to 230 centimeters [cm]) below the sediment surface (see Figure 3-5). Analysis of the 2008 low resolution coring (LRC) dataset indicates peak concentrations for several contaminants are deepest downstream of RM 8 (see Appendix A).

Buried peak concentrations are also observed in the five high resolution cores collected by USEPA in 2005. Cesium-137 (Cs-137) profiles in these cores (collected at RMs 1.4, 2.2, 7.8, 11, and 12.6) are shown on Figure 3-6a. Cesium in sediments is derived from atmospheric nuclear weapons testing. The first occurrence of cesium in sediments generally marks the year 1954, and peak concentrations correspond to 1963, the year maximum atmospheric fallout from testing was noted (Chaky 2003). The vertical contaminant distributions are presented on Figures 3-6b through 3-6g. These plots suggest the following:

- The timing of peak loadings varies by contaminant.
- The width of the peak can be used to estimate the length of time the peak loading occurred; narrower and sharper peaks of 2,3,7,8-TCDD and Total PCBs compared to metals, for example, suggest that metals were discharged for a longer period of time compared to 2,3,7,8-TCDD and Total PCBs. The lack of well-defined PAH peaks suggest an even more temporally distributed loading.
- All contaminants show a notable decline in the post-1963 era, which may be related to source control measures following the passage of the 1972 Federal Water Pollution Control Act amendments.

3.2.2 Surface Water

Surface water data presented herein were collected as part of the small-volume CWCM program. Future analyses will also include the large-volume CWCM data collected in 2012 and 2013. The CWCM measures physical parameters and contaminant concentrations at stations across the LPR and Newark Bay, the UPR at Dundee Dam, the Kills, the Hackensack River, and several LPR tributaries (see the CWCM Quality Assurance Project Plan; AECOM 2011b). As of July 2013, validated data are available for six low to moderate flow sampling events conducted in 2011 and 2012; the flows, tidal ranges, and 2,3,7,8-TCDD data counts are summarized in Table 3-2.

Total water column 2,3,7,8-TCDD, PCB, and mercury concentrations as a function of total suspended solids (TSS) are shown on Figure 3-7. A strong correlation is observed for these contaminants particularly within the LPR[4], indicating that the particulate phase dominates water column contaminant levels. The spatial distributions of these contaminants in the water column (normalized to TSS) are shown on Figures 3-8a through 3-8c. These plots also show mean surface sediment concentrations[5]. Key observations within the LPR include the following:

- Mean water column concentration trends are similar to those of surface sediments, though there are variations near the Newark Bay boundary for mercury. This suggests that resuspension of surficial solids from the sediment bed drives the water column contaminant concentrations. See Sections 5.1, 5.2, and 5.3 for more discussion of resuspension processes.
- Water column contaminant concentrations are generally lower than surface sediment concentrations. The reasons for this observation are being investigated in the context of contaminant fate and transport processes (see Section 5.3).

[4] Within Newark Bay, there is greater scatter in the relationship between contaminant concentration and TSS, presumably reflecting a greater mixing of solids from different origins (i.e., the LPR, the other Newark Bay tributaries, and locally resuspended sediments). Mean water column concentrations are also closer to the mean bed concentrations in Newark Bay than in the LPR. The contaminant exchange between the LPR and Newark Bay is under investigation as part of the development of the RI/FS Contaminant Fate and Transport Model, and will be addressed in future updates.

[5] The sediment data downstream of RM 10 is binned to the closest water column sampling location. Sediment data upstream of RM 10 is binned as follows: RMs 10 to 12, RMs 12 to 14, and RMs 14 to 17.4.

Additional analyses[6] of the CWCM data are ongoing and will be included in future reports once completed.

3.2.3 Tissue

Contaminant concentrations in eel filet and blue crab muscle are shown together with surficial sediment concentrations on Figures 3-9a through 3-9c. Eel filet and blue crab were chosen given the spatial coverage of available data throughout much of the LPR relative to other biota. For these figures, 2,3,7,8-TCDD and Total PCB concentrations are normalized to lipid contents, and mercury concentrations are shown on a wet weight basis. The tissue data are presented this way because mercury binds with the thiol (-SH) group of the amino acid cysteine; whereas the 2,3,7,8-TCDD and PCBs accumulate in tissue lipids. The general trends seen here are similar to surface sediment concentrations, suggesting that the surface sediments drive biota contaminant concentrations, either through a direct pathway or via water column sources that are derived from the sediments. The exception seems to be mercury concentrations in blue crab muscle in RM 0 to RM 2—the value seems higher than those further downstream, and is also higher than the corresponding sediment concentration. The reason for this needs to be further investigated.

3.3 External Sources

External sources[7] to the LPR include the UPR (i.e., above Dundee Dam), Newark Bay, major tributaries, CSOs/SWOs and other National Pollutant Discharge Elimination System (NPDES) permitted discharges, and direct runoff. The relative influence of internal and external sources on LPR contaminant concentrations is still being studied via the development of the numerical chemical fate and transport model for the LPR and Newark

[6] Examples of ongoing analyses of chemical water column data include the influence of particulate organic carbon on contaminant spatial trends, station-specific responses to flow and tidal conditions, and contaminant loading to the LPR and Newark Bay at boundaries.

[7] Contaminant loadings from groundwater and atmospheric sources are not explicitly considered here. Rather, it is assumed that loadings from these sources would mainly enter the LPR as part of the total contaminant load entering from the upstream boundary at Dundee Dam, from the downstream boundary at RM 0, and from tributary/CSO inflows. Specific groundwater or atmospheric sources exerting a concentrated, local influence on the LPR have not been identified at this time.

Bay and analyses of the CWCM data; however, insights regarding the potential importance of external sources and the associated recontamination on the LPR can be gleaned by comparing surface sediment contaminant concentrations from these external sources to those in LPR sediments.

Surface sediment contaminant concentrations in the LPR and its external sources are compared in the probability distributions shown on Figures 3-10a and 3-10b. For all contaminants except 2,3,7,8-TCDD, the concentration distributions in the LPR and its external sources are similar, suggesting the external sources have some influence on concentrations in the LPR sediments (ongoing modeling efforts will help in estimating the magnitude of this influence). 2,3,7,8-TCDD concentrations, on the other hand, are more than an order of magnitude higher in the LPR than the external sources, suggesting that potential external sources of 2,3,7,8-TCDD have a much lesser effect on concentrations in the LPR sediments.

3.3.1 Upper Passaic River and Newark Bay

The ratio of average, OC-normalized, surficial sediment contaminant concentrations for the Lower LPR to UPR and Upper Newark Bay for the post-2000 dataset is shown on Figure 3-11. As discussed in Section 3.2.1, contaminant concentrations in the Lower LPR are relatively uniform, thus, these ratios are helpful in characterizing the possible influence of upstream and downstream sources, and the potential for recontamination from these sources following Lower LPR remediation. The magnitude of the influence is governed by the importance of UPR or Newark Bay solids to the surface sediment balance (which is currently being investigated). The patterns on Figure 3-11 indicate the following:

- Lower LPR/UPR ratio of much greater than one suggests that the UPR is not contributing significantly to Lower LPR contaminant concentrations. For contaminants that fall into this category, the potential of recontamination from the UPR to present day levels after Lower LPR remediation is minimal.
- Lower LPR/UPR ratio of approximately one or less suggests that the UPR might be partially contributing to Lower LPR contaminant concentrations. This suggests some likelihood of recontamination from the UPR after Lower LPR remediation for these

contaminants, and little long-term benefit could be expected from remediation unless upstream sources are controlled.

- Lower LPR/Upper Newark Bay ratio is also indicative of similar conclusions. The contribution of Upper Newark Bay solids to the Lower LPR surface sediment budget is likely different from the contribution of UPR solids (and is subject to ongoing investigation via numerical modeling and the CWCM and Physical Water Column Monitoring [PWCM] programs).

For 2,3,7,8-TCDD, the average surface sediment concentration in the Lower LPR is substantially higher than those in the UPR and Upper Newark Bay (approximately 75-fold and 8-fold, respectively). This highlights the importance of in situ LPR sediments as opposed to potential external sources, and suggests there is little potential for recontamination to present levels for TCDD upon Lower LPR remediation. All other contaminants show more comparable Lower LPR and UPR/Upper Newark Bay concentrations, indicating a higher recontamination potential.

3.3.2 Tributaries and Other Point Sources

Tributaries, CSOs/SWOs, and other point sources (e.g., industrial and municipal discharges) have the potential to be ongoing sources to the LPR sediments. Comparison of surface sediment concentrations in LPR tributaries[8] to those in LPR sediments within 0.2 mile of the confluence is shown on Figure 3-12. A ratio of tributary to LPR sediment contaminant concentration near or greater than one indicates the potential for localized impacts from these tributaries[9]. These comparisons suggest that for many contaminants, one or more tributaries have the potential to contribute to elevated contaminant levels at least locally within the LPR.

[8] Only tributary samples collected above the head of tide (HOT) are included in these analyses. Samples collected below the HOT would be influenced by the same tidal phenomenon impacting the LPR and are thus not representative of the tributary source. Limited contaminant data collected downstream of HOT do not show any high contaminant concentrations.

[9] The ratio of Saddle River to Lower LPR sediment 2,3,7,8-TCDD concentrations is greater than 1, however, actual 2,3,7,8-TCDD concentrations in the Saddle River are orders of magnitude lower than elsewhere in the Lower LPR.

Various studies and data reviews (e.g., Huntley et al. 1997; Shear et al. 1996) suggest that CSOs are a source of a broad range of contaminants to the LPR and that CSO-specific signatures can be found in the local sediments, thus suggesting the local importance of these CSO discharges. However, detailed information on CSO loadings is currently not available. Additional data may in the future possibly be provided by planned CSO data collection efforts.

Industrial and municipal discharges have the potential to serve as local sources of contaminants to the LPR. However, information related to these discharges is limited and further investigation would be needed to understand the relative importance of these potential sources.

3.4 Other Stressors

Due to its urban nature, the LPRSA and its ecological community are subject to a variety of non-chemical stressors, including invasive species, organic inputs, nutrients, and anthropogenic changes (e.g., dams, bulkheads) that alter its salinity structure. A discussion of several of each type is provided in this section.

Salinity plays a significant role in controlling the structure and function of the benthic community. The benthic community will change as the salinity changes depending on the tolerances of the organisms. The ETM, characterized by high levels of suspended particles, is typically located near the downstream side of the salt front in an estuary system such as the LPR. The dynamics of the communities change as a result of these salinity changes. Anthropogenic salinity stress may occur as a result of various anthropogenic actions. For example, alterations in flow may reduce the influx of freshwater, resulting in changes in salinity downstream and impacts on the adapted invertebrate community (Copeland 1966). Dredging and channelization can also alter the influx of saline waters into an estuary (Navarrina et al. 2008).

Increased organic input has affected the LPRSA benthic community. Sediment profiling imagery taken in 2005 (Germano and Associates 2005) indicates that the system is highly enriched by organic inputs such as leaf litter and urban runoff. The amount of total organic carbon (TOC) in the sediment directly influences the benthic community structure and function (Pearson and Rosenberg 1978; Borja et al. 2008; Carvalho et al. 2005, 2011). Although organic matter is an important food source to benthic organisms, too much can cause changes in the benthic community structure (Diaz and Rosenberg 1995) by affecting the species richness and abundance due to oxygen depletion and buildup of toxic by-products such as ammonia. It also influences the bioavailability of chemicals. The TOC in the LPR ranges up to 24 percent (with a mean value of approximately 4 percent; Windward 2011d), so the influence on the benthic community is very likely; a previous study has indicated that TOC in excess of 3.5 percent may result in significantly decreased benthic diversity (Hyland et al. 2005)[10]. Organic debris (e.g., leaf litter) was also observed in many of the sediment samples and may also be influencing the benthic community structure (Windward 2011b). Seasonal depressions of DO, as well as daily swings, are not uncommon in riverine environments and are often related to natural phenomena (i.e., diurnal patterns in photosynthesis) or nutrient enrichment (NJDEP 2008). Recent water column DO monitoring in the LPR and above Dundee Dam (Windward 2012c) suggest that DO in the LPR water column is depressed seasonally (i.e., less than approximately 3 to 5 milligrams per liter) for short intervals, particularly during warm months and in saline waters. However, it does not drop below the NJDEP water quality criteria[11] when averaging measured DO levels over 24-hour periods under the flow conditions that occurred during the monitoring interval.

The Hilsenhoff Biotic Index for the LPRSA (Windward 2011b) suggests that the system is highly enriched by organic inputs (Germano and Associates 2005). This is indicative of communities in highly enriched systems (Hilsenhoff 1987). The LPRSA benthic community may have reduced diversity due to elevated nutrients such as phosphorus and nitrogen and changes in the benthic diversity due to constituents such as ammonia[12]. A TMDL for

[10] Sediment associated with Sediment Quality Triad samples (for which benthic community data are available) did not exceed 7 percent TOC; the mean value of TOC was less than 3.5 percent.
[11] NJDEP surface water quality criteria for DO is 5.0 milligrams per liter (mg/L; 24-hour average) but not less than 4.0 mg/L for surface water in the LPR from the outlet of Osborn Pond (upstream of Dundee Dam) to the confluence with the Second River and not less than 3.0 mg/L from the confluence with the Second River to the mouth of the LPR (New Jersey Administrative Code 7:9B).
[12] Refer to Section 4.1.3.1 for more information regarding the benthic community in the context of the CSM.

phosphorus was adopted by NJDEP in 2008 for the freshwater, non-tidal portion of the Passaic River Basin upstream of Dundee Dam to meet the Surface Water Quality Standards pursuant to the Water Quality Planning Act at N.J.S.A. 58:11A-7 and the Statewide Water Quality Management Planning rules at N.J.A.C. 7-16-6.4(a), as well as compliance with Sections 305(b) and 303(d) of the CWA. Excess phosphorus (i.e., above the Surface Water Quality Standards) can lead to excess primary productivity and associated swings in pH and DO, which can cause additional stress and adverse effects on the aquatic community. In the LPRSA, increasing phosphorus and nitrogen were correlated with decreasing benthic diversity indices (Windward 2011b).

A key nuisance species found in the LPRSA is the common carp (Cyprinus carpio). The common carp is a non-native species of cyprinid fish that has in many regions around the world been linked to observable adverse impacts on aquatic habitats and the suitability of that habitat for both aquatic and terrestrial wildlife (Wahl et al. 2001; Industry & Investment NSW 2010). These impacts are primarily attributed to the carp's method of feeding, which disturbs the sediment and increases turbidity, and the direct ingestion of macrophytes and submerged vegetation. This behavior results in reduced biomass and growth of submerged vegetation as well as reduced biodiversity and can lead to shifts in the autotrophic community away from aquatic submerged vegetation and filamentous algae to suspended algae. Also, consistent resuspension of sediment and egestion can result in an increase in available phosphorus and nitrogen (Chumchal et al. 2005), which can foster rapidly growing unicellular algae (Chumchal et al. 2005; Weber and Brown 2011) that can further diminish light penetration, thereby creating a positive feedback loop that disfavors submerged vegetation. The benthic community shifts from species that utilize submerged vegetation for food or refuge (i.e., amphipods and hirudineans) to those that consume OC directly from sediment (i.e., oligochaetes and chironomids; Miller and Crowl 2006). This effect of carp on an invertebrate community may be partially responsible for the significant correlation found between carp abundance[13] and crustacean, chironomid, and annelid abundance[14] in the LPRSA.

[13] Carp abundance data from the LPR may be biased spatially due to the collection methods.
[14] This statement is based on recent explorations of field survey data by Windward Environmental, LLC, which have not been reported elsewhere to date. As assessed in 2009 (Windward 2011b), annelid abundance in the LPR is most often dominated by oligochaetes, and crustacean abundance was most often dominated by amphipods. In the LPR, carp abundance (summed by RM; also measured in 2009) was positively correlated with annelid abundance and negatively correlated with crustacean abundance (summed by RM).

4 RISK RECEPTORS AND PATHWAYS

This section describes the ecological and human health risk assessment components of the CSM. The bases for the current discussion are the USEPA-approved Problem Formulation document (PFD; Windward and AECOM 2009), Risk Analysis and Risk Characterization (RARC) Plan (Windward and AECOM in preparation), and more recent biological surveys conducted under USEPA oversight. Recognizing the unique characteristics of the LPRSA is critical to developing an accurate understanding of ecological and human receptors and their potential interactions with environmental media. Site-specific factors, including urbanization, mixed land uses, non-chemical stressors, hardened/altered shorelines, and the estuarine environment, influence receptors in the LPRSA and pathways of exposure to site-related contamination. Both risk assessments are currently being performed.

- Key ecological receptors include aquatic organisms such as the benthic community, fish, and their predators.
- Primary potential human health receptors are recreational users (anglers, boaters, and waders) and workers.
- Key human health exposure pathways include direct contact/uptake from surface water and surface sediment (particularly nearshore/mudflat areas) and consumption of fish and/or crab.
- Both chemical and non-chemical stressors play a role in toxicity and risk.
- Preliminary data evaluations suggest that 2,3,7,8-TCDD is the major human health risk driver and can also result in potential risks to some ecological receptors.
- Other bioaccumulative compounds, including PCBs, pesticides, and mercury, also contribute to both ecological and human health risks but to a lesser extent.
- Urban background conditions contribute to cumulative risk burden for ecological and human receptors.

4.1 Ecological

The ecological setting of the LPRSA is typical of urban systems, with reduced habitat quality and increased urban inputs, and has been extensively described previously (Germano and Associates 2005; Iannuzzi et al. 2008; Iannuzzi and Ludwig 2004; Ludwig et al. 2010; Windward and AECOM 2009, 2012; Baron 2011). To determine which organisms to assess for potential ecological risk, it is critical to understand this setting and habitat types within and adjacent to the river. The ecological CSM is central to the ecological risk assessment and the ultimate remedy selection.

The quality of the ecological habitat has been severely impaired. The historical and current industrial use and residential development of the shoreline (particularly in the lower portion of the LPR) have limited the shoreline habitats. The LPR shoreline can be divided into the following: 1) a lower portion (RM 0 to RM 8) that is largely characterized by a developed shoreline with structures abutting industrial properties; and 2) an upper portion (RM 8 to RM 17.4) that is characterized by mixed vegetation abutting roads, parks, and residential properties. Access to the west bank of this stretch of the river is limited by State Route 21.

4.1.1 Ecological Receptors

A USEPA-consistent process was used to select preliminary representative receptor species based on the biological surveys and other information (e.g., habitat data) from the LPRSA and the surrounding area. Factors considered in this selection include the following:

- Potential for exposure to contaminated site sediments
- Relative ability to bioaccumulate/biomagnify site-related chemicals
- Societal and cultural significance (including species highly valued by society)
- Ecological significance (including species serving a unique ecological function)
- Sensitivity to site-related chemicals

The ecological receptor groups for the Baseline Ecological Risk Assessment (BERA) include the following (see Table 4-1):

- Zooplankton community
- Benthic invertebrate community (i.e., multiple infaunal species)
- Macroinvertebrate populations (i.e., blue crab)
- Mollusk populations (i.e., ribbed mussel and freshwater mussel)
- Fish populations (i.e., mummichog, banded killifish/darter, white perch, channel catfish/brown bullhead[15], American eel, and largemouth bass[16])
- Bird populations (i.e., mallard duck[17], spotted sandpiper, heron/egret, and belted kingfisher)

[15] White catfish were also collected during the late summer/early fall 2009 sampling effort and will be used in the evaluation of freshwater invertivorous fish per USEPA's request.

[16] Smallmouth bass and northern pike were also collected during the late summer/early fall 2009 sampling effort and will be used in the evaluation of freshwater piscivorous fish per USEPA's request.

- Mammal populations (i.e., river otter[18])
- Aquatic plant community
- Amphibian populations
- Reptile populations

Exposure of ecological receptors to chemicals could be through contact (e.g., direct contact of benthic organisms to sediment), ingestion of water or sediments, or ingestion of contaminated prey. Several of the ecological receptors in the LPRSA utilize the mudflat habitat (e.g., spotted sandpiper). In tidal rivers such as the LPR, intertidal and shallow subtidal areas are an important and productive habitat. Many ecological receptors, including the spotted sandpiper and wading birds, feed primarily along mudflats and other shallow areas. Forage fish, which serve as a food source for larger fish, mammals, and birds, also utilize shallow water areas for feeding and refuge. A complete exposure pathway will have a route for a chemical to travel from the source to the ecological receptors and be taken up by them. The potential chemical exposure pathways were evaluated for all receptors (see Table 4-1) to determine which pathways will be evaluated as part of the BERA.

4.1.2 Assessment and Measurement Endpoints

The Screening Level Ecological Risk Assessment (SLERA), prepared as directed by the USEPA, has identified numerous contaminants of potential ecological concern, including metals, PAHs, dioxins and furans, PCBs, and pesticides. Assessment endpoints, risk questions, and measurement endpoints will be used to define the evaluation of risks in the BERA. USEPA (1998) defines assessment endpoints as "explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes." The BERA for the LPRSA will be based on a community- or population-level assessment and will evaluate the following:

[17] The mallard duck is not proposed to be a quantitatively evaluated receptor because the potential exposure to chemicals is expected to be higher for other higher-trophic-level avian receptors (i.e., invertivores and piscivores).

[18] The selection of the river otter may be overly conservative for the protection of mammals that currently use habitat along the LPR.

- Maintenance of the zooplankton community that serves as a food base for juvenile fish
- Protection and maintenance (i.e., survival, growth, and reproduction) of the benthic invertebrate community, both as an environmental resource in itself and as one that serves as a forage base for fish and wildlife populations
- Protection and maintenance (i.e., survival, growth, and reproduction) of healthy populations of blue crab and crayfish that serve as a forage base for fish and wildlife populations and as a base for sports fisheries
- Protection and maintenance (i.e., survival, growth, and reproduction) of healthy mollusk populations
- Protection and maintenance (i.e., survival, growth, and reproduction) of omnivorous, invertivorous, and piscivorous fish populations that serve as a forage base for fish and wildlife populations and as a base for sports fisheries
- Protection and maintenance (i.e., survival, growth, and reproduction[19]) of herbivorous, omnivorous,[20] sediment-probing, and piscivorous bird populations; use of LPR habitat for breeding used to determine the relative weight for the bird egg measurement endpoint
- Protection and maintenance (i.e., survival, growth, and reproduction) of aquatic mammal population
- Maintenance of healthy aquatic plant populations as a food resource and habitat for fish and wildlife populations
- Protection and maintenance (i.e., survival, growth, and reproduction) of healthy amphibian and reptile populations

[19] Few aquatic birds currently use the LPR for breeding because of the existing habitat constraints. The reproduction assessment endpoint for birds will evaluate whether existing chemical concentrations will impact reproduction if suitable habitat were present.

[20] Consistent with the PFD (Windward and AECOM 2009), omnivorous birds were not identified in the CSM as a feeding guild to be quantitatively evaluated. A representative species was not selected because the evaluation of other avian feeding guilds (i.e., sediment-probing and piscivorous birds) will be protective of omnivorous birds.

4.1.3 Ecological Conceptual Site Model

An ecological CSM is used to describe the pathways by which contaminants move from sources, including those resulting from human activities, to ecological receptors at a site. The USEPA (and partner agencies)-approved ecological CSM (Windward and AECOM 2009) for the LPRSA is based on site-specific information about species typically present at the site or similar urbanized river systems and potential exposure pathways. The ecological CSM will be updated in the BERA as additional data are obtained. The general ecological CSM is presented on Figure 4-1. Focal species identified here will be evaluated according to the area(s) where they were found (in some cases, the entire LPRSA). The ecological food web is depicted on Figure 4-2. Benthic, fish, and bird communities are discussed in the following sections.

4.1.3.1 Benthic Community

The benthic invertebrate community of the LPRSA primarily comprises pollution-tolerant species of the oligochaete and polychaete classes (Germano and Associates 2005; Iannuzzi et al. 2008). These were also the two dominant classes found in the fall 2009 (Windward 2011b) and spring and summer 2010 (Windward 2012a) seasonal surveys (see Figure 4-3). Polychaetes dominated the estuarine zone, and oligochaetes dominated the freshwater zone (see Figure 4-3). The distributions of polychaetes and oligochaetes are consistent with seasonal trends in interstitial salinity, which vary with the input of freshwater from storm events, generally beginning in the fall and lasting through the spring. Oligochaetes are distributed throughout the river; however, their contribution to the total abundance of benthic invertebrates increases between RM 0 and RM 4 as freshwater inputs increase (see Figure 4-4). The benthic invertebrate community is composed of very few oligochaetes below RM 4 during the summer when freshwater inputs are lower. The ecological salinity zones in the river are, in general, estuarine (RM 0 to RM 4), transitional from estuarine to freshwater, depending on season and freshwater input (RM 4 to RM 8.5), and freshwater (above RM 8.5).

Germano and Associates (2005) noted that benthic communities at the mouth (RM 1, Kearney Point) were either highly disturbed (physical disturbances such as erosion or deposition) or stratified (surface feeding opportunistic feeders found in recently disturbed environments in conjunction with deeper dwelling deposit feeders indicative of less disturbed areas). Communities appeared to be recently disturbed or in early transitional stages through the estuarine and transitional zones (to approximately RM 9). The few 2005 study stations that had mature communities were stratified with early communities deposited over mature communities. Undisturbed (i.e., not stratified) mature communities were mostly present in depositional areas between RM 9 to RM 15. Frequent physical disturbance of benthic communities is often observed in urban streams as a result of channel modifications and upland land use (e.g., impervious pavement and increased stormwater inputs; Walsh et al. 2005). In the LPRSA, the surficial estuarine sediment is often disturbed due to physical processes such as erosion and deposition (see Section 5.2 for a discussion of erosion and deposition cycles). Germano and Associates (2005) concluded that the estuarine portion of the LPRSA (particularly near Newark Bay) receives heavy organic loading (evidenced by underlying sediment characteristics such as anoxia, dark color/oxygen demand, and methanogenesis).

A recent study characterizing the presence of species by size, opportunistic behavior, longevity, and burrowing depth (Windward 2011b) suggests that most stations in the LPRSA, particularly above RM 6.5, either contain mature communities or are transitioning into mature communities[21]. More stations are categorized with perturbed communities below RM 6.5, especially in RM 2 to RM 5. A number of stations within RM 2 and RM 3 appear to be recently disturbed based on the predominance of early successional stage-associated benthic invertebrate species. At the mouth of the LPR (RM 1), communities are mature or transitioning into mature. Mixed, stratified sediment with early stage communities in conjunction with deeper dwelling mature communities are found in RM 1, between RM 5 and RM 7, and in RM 13 (see Figure 4-5).

[21] The calculation of community successional stage, using data from Windward (2011b), specifically addresses physical processes. Mature communities have not been frequently disturbed by erosion and deposition, as evidenced by the prevalence of associated species. This association is based on the life strategies of individual taxa. Long-lived, deep-burrowing, large-bodied, and non-opportunistically feeding taxa are found in infrequently disturbed sediment, whereas short-lived, rapidly reproducing, small, and opportunistically feeding species tend to be associated with early communities. Tolerance to pollution was not included in the categorization of taxa.

The distribution of benthic successional stages in the LPRSA is likely driven, at least in part, by the physical processes detailed in Section 5.2. Stations with mature communities in the upper estuarine zone and transition zone (approximately RM 5 to RM 9) are less diverse and are dominated by more tolerant, less abundant, and deeper burrowing oligochaete and polychaete annelids. Diversity increases above RM 10. Stations in the lower estuarine zone (below RM 5) are dominated by transitional communities but have higher diversity than the upper estuarine and transitional zones. This might be an indication of organic loading stress and matches observations by Germano and Associates (2005).

Salinity is the primary influence on the benthic community; OC, grain size, and other habitat characteristics are secondary influences. The benthic community is typical of an urban estuarine system in the lower reaches of the LPRSA and a more typical freshwater community in the upper reaches of the LPRSA (see Figure 4-6). The transition zone has a decrease in benthic diversity and richness (see Figure 4-7). This area is more prone to changing conditions, and thus, less benthic organisms adapt to these conditions. The distribution of major taxa by RM is shown on Figure 4-8.

The freshwater benthic community Hilsenhoff Biotic Index for the LPRSA is indicative of communities in highly enriched systems (Hilsenhoff 1987); 94 percent of freshwater LPRSA stations[22] (Windward 2011b) have "severe organic pollution" and "very poor" water quality based on the index (i.e., mean value of 8.51 to 10; Hilsenhoff 1987). The LPRSA benthic community may have reduced diversity due to elevated nutrients such as phosphorus and nitrogen and changes in the benthic diversity due to constituents such as ammonia. Preliminary toxicity test results indicate a range of responses associated with both chemical stressors and habitat characteristics such as OC.

4.1.3.2 Fish Community

Twenty-two fish species were collected during the 1999 to 2000 surveys (Iannuzzi and Ludwig 2004). The most commonly collected fish species was mummichog; other common

[22] The elimination of methodologically different kick-net samples from the collection of all samples increases the percentage of freshwater LPR stations with a "very poor" index score to approximately 98 percent (Windward 2011b; Hilsenhoff 1987).

species included inland silverside, white perch, Atlantic menhaden, striped bass, and gizzard shad. During the late summer/early fall 2009 sampling, American eel, white perch, and common carp were the dominant fish species caught, and relatively few mummichog, darter, or killifish species were caught. However, these species were caught in abundance during the late May to early August 2010 field efforts. These efforts focused on the collection of small forage fish (Windward 2010). The fish abundance by season for the 2009 and 2010 surveys is shown on Figure 4-9.

Unlike the benthic community, fish and crab communities use the river regardless of salinity, with the exception of the extreme ends of the salinity ranges (i.e., near RM 0 there will be estuarine fish, and in the upper reaches there will only be freshwater fish). Small forage fish feed in the shallow nearshore habitat (e.g., mudflats)—these areas, thus, also provide preferential feeding habitat for fish, birds, and mammals (see Figure 4-10).

4.1.3.3 Bird Community

Forty-nine bird species were observed during the 1999 to 2000 surveys (Iannuzzi and Ludwig 2004). Gulls, ducks, and swallows were dominant along the lower portion of the LPRSA (Ludwig et al. 2010), whereas gulls, ducks, and geese dominated during the summer and fall 2010 surveys (Windward 2012b). Both surveys found that shorebirds were most often observed on mudflats or shorelines, whereas ducks and geese were most commonly observed on the water. Gulls and terns were observed on the water or manmade structures, and wading birds preferred the shoreline (Ludwig et al. 2010). Sediment-probing shorebirds use mudflat habitats along the LPRSA, and piscivorous birds (e.g., heron/egret and belted kingfisher) have also been observed primarily on manmade structures seasonally along the LPRSA and its tributaries (Windward 2011b, 2011c). There is little to no evidence of these bird species using the LPRSA during breeding (Ludwig et al. 2010; Baron 2011). Avian species observed in the LPRSA are presented on Figure 4-11. As illustrated on Figure 4-1, the surface sediment and surface water pathways, as well as tissue ingestion for higher trophic organisms, are the primary pathways for exposure to ecological receptors. These receptors may ingest sediment at the surface while probing for food, ingest or have direct contact with surface water, and ingest fish or invertebrates that may be exposed to surficial sediments via foraging behavior.

4.2 Human Health

This section describes the human health CSM for the LPRSA, previously discussed in the PFD (Windward and AECOM 2009) and RARC Plan (Windward and AECOM in preparation). The development of the human health CSM took into account the site setting and land uses, physical characteristics, potential human receptors, and their potential pathways of contact with affected media. The human health CSM focuses on potential exposure to contaminants in LPRSA sediments, surface water, and biota and reflects a consensus of understanding with USEPA and the partner agencies regarding exposure scenarios warranting quantitative evaluation in the baseline Human Health Risk Assessment (HHRA). However, specific exposure assumptions established for the baseline HHRA (RARC Plan [Windward and AECOM in preparation]) reflect hypothetical future conditions associated with a restored river conducive to recreational activities such as swimming. Activities involving frequent or extended exposures to sediment, surface water, and biota are currently limited for many reasons, as discussed subsequently.

Land use along the LPRSA varies considerably (see Figures 4-12a to 4-12f). The lower portion of the river is dominated by high-density commercial and industrial development and rail/transportation infrastructure (see Table 4-2). A strip of greenspace (Riverbank Park and Minish Park) runs along the western bank of the river between RM 4 and RM 5 in Newark. The shoreline along much of the lower 7 miles is bulkheaded. Physical constraints and the primarily industrial/commercial, urban, and infrastructure land uses limit both access and exposure to sediment and surface water in the lower 7 miles[23]. Land use transitions to increasingly commercial and recreational upriver, with residential pockets above RM 8. The western bank between RM 7 and RM 14 is limited to public access by NJ Route 21—a four-lane highway running parallel to the river. The eastern bank of the river between RM 7 and RM 14 has several parks and boathouses. Future redevelopment plans include revitalizing existing parks and increasing open spaces along the riverfront, although the resulting change in shoreline access is unclear. The potential for exposure to accessible

[23] Accessible sediment is defined as surface sediment beneath 2 feet or less of water at MLW, using USACE nominal MLW of -2.3 feet National Geodetic Vertical Datum 1929 (NGVD29; in the PFD [Windward and AECOM 2009]).

sediment and surface water is greater in the recreational and residential areas above RM 7, where direct access to the eastern banks of the river is possible.

Recreational activities are largely limited to those with low potential for direct contact with river sediment and surface water. Several local boat clubs and rowing associations maintain boat docks between RM 8 and RM 12 (see Figures 4-12a to 4-12f). The rowing season runs from early spring into late fall, during which sculls travel as far downriver as RM 4 and as far upriver as RM 16. Pleasure boating is limited, except for occasional canoes and kayaks, due to several low-clearance bridges and limited public boat ramps. There are no public beaches or swimming areas on the river. The urban setting and presence of trash, debris, and CSOs discharging into the river are visible deterrents to swimming and other high-contact water sports. Although the state's classification of the freshwater portion of the river (from the confluence with Second River to Dundee Dam) includes swimming as a designated use, this stretch of the river frequently does not meet the pathogen standards associated with this classification (NJDEP 2012).

Fishing has been observed, with most activity above RM 9 (predominantly freshwater reach). An advisory prohibiting the sale or consumption of shellfish and advising against the consumption of all species of fish has been in effect since the 1980s (NJDEP and New Jersey Department of Health and Senior Services 2012). Based on a 2011 to 2012 Creel/Angler Survey (CAS) of the LPRSA, most anglers heed that advisory and use catch-and-release practices. Some of the anglers with kept catch reported the fish would be shared with one other person, although no kept catch was to be shared with children or pregnant or nursing women. Species that anglers reported they would keep include striped bass, common carp, channel catfish, white perch, smallmouth and largemouth bass, northern pike, American eel, and brown bullhead. The study found no anglers keeping crabs. About 95 percent of anglers are male, with an average age of 40, and represent a mix of races/ethnicities, including Caucasian, Hispanic, African American, and Asian/Pacific Islanders. Most of these anglers live within 5 miles of the LPRSA and fish between April and November. The CSM may be updated with further CAS data analyses to incorporate new site-specific information and expanded understanding of the angler behaviors.

Human receptors at the LPRSA include recreational anglers, boaters, waders, workers, and residents with properties abutting the river. Transients and homeless individuals have also been observed. These receptors may be exposed to site-related contaminants while engaging in activities that bring them in direct contact with nearshore or mudflat sediments and surface water (i.e., through incidental ingestion or dermal contact). Direct contact with deeper sediments away from the shoreline is not expected to occur under typical exposures and activities on the river. Recreational anglers who do not practice catch-and-release may be exposed to bioaccumulative chemicals such as dioxins and furans, PCBs, mercury, and various pesticides from consuming LPRSA fish or crab. Potential exposure via inhalation is negligible given that the dominant contaminants are not volatile. Figure 4-13 presents a schematic of potential sources, exposure media, exposure pathways, and receptors for the human health CSM.

The presence of bioaccumulative contaminants, including dioxins/furans, PCBs, mercury, and various pesticides, in LPRSA fish and crab has been documented (Windward 2011e), as discussed in Section 3.2.3. Due to the presence of bioaccumulative contaminants in biota and the CAS finding that a small percentage of LPRSA anglers consume their catch, human health risk is expected to be dominated by consumption of LPRSA fish and crab.[24] The baseline HHRA is currently being performed, however, preliminary data evaluation suggests that human health risks from consumption of LPRSA fish and crab are driven by 2,3,7,8-TCDD. To a lesser extent, PCBs, mercury, and pesticides are potential contributors.

The presence of various pathogens (bacteria, protozoa, and viruses) in CSO discharges and LPRSA media has been documented (Exponent 2004; Interstate Environmental Commission 2003; New Jersey Harbor Dischargers Group 2012; New York-New Jersey Harbor and Estuary Program 2006), and the potential risk to humans from microbial exposures in surface water and sediment has been found to be significant (Donovan et al. 2008a, 2008b). Pathogens, as well as external sources of chemical contaminants present in the LPRSA (see Section 3.3), influence background conditions that contribute to human health risks.

[24] The 2011 to 2012 CAS did not find anglers catching and keeping LPRSA crab. At the direction of USEPA, potential contaminant exposure via crab consumption is evaluated in the baseline HHRA.

In summary, for the primary exposure pathways (i.e., direct contact with surface water, direct contact with nearshore/mudflat surface sediment, and ingestion of biota), site-specific factors, including hardened/bulkheaded shoreline throughout much of the lower 6 miles and the western bank; absence of areas conducive to swimming; presence of visible trash, debris, and numerous outfalls; pathogenic contamination; and advisories warning against consumption of all fish and crab throughout the Study Area, tend to limit human exposures to site-related contaminants.

5 FATE AND TRANSPORT

Contaminants in the LPR are subject to various processes, including the following:

- Tidal processes: Tidal currents cause periodic resuspension and deposition of a "mobile pool" (Geyer 1993) of fine sediments that exist as a "fluff layer" (a thin veneer of unconsolidated sediments). The flood-dominance of tidal currents induces a net upstream "tidal pumping" of solids in the estuarine portion of the LPR. The salinity intrusion also induces a mean flow structure (the estuarine circulation) that transports solids upstream along the bottom of the estuary. These processes dominate during low to moderate flow conditions and give rise to infilling conditions.
- Event-driven scour: High flow events flush the system and induce a net downstream solids transport. Under sufficiently high flows, this may result in localized sediment scour and contaminant mobilization from deeper sediments to the surface.

- Solids and contaminant transport are strongly influenced by freshwater flow and tidal pumping. Major fate and transport mechanisms include tidal resuspension/deposition, event-driven scour/redistribution, deposition/burial, sediment bed exchanges (mixing), and boundary loadings.
- Historically, the Lower LPR and Upper Newark Bay have been an effective contaminant trap. Areas where dredging has ceased to be maintained have experienced significant deposition and contributed to contaminant burial and trapping.
- Cs-137 profiles coincident with contaminant concentration peaks suggest that many of the contaminated areas in the LPR are static and relatively stable.
- Net upstream contaminant transport may occur within the LPR to approximately RM 14 (declining with distance upstream).
- The highest surface concentrations of 2,3,7,8-TCDD, Total PCBs, and mercury are all observed in mudflats upstream of RM 8.
- Low to moderate flow water column measurements of 2,3,7,8-TCDD during CWCM suggest the following:
  - Within the LPR, the local sediment bed is the dominant water column source.
  - Within the LPR, tidal resuspension of solids controls low flow water column concentrations.
  - Fluff layer-parent bed interactions are likely important within the LPR at low flow.
  - Mixing of solids and contaminants occurs between Newark Bay and the LPR. Settling and dilution cause the 2,3,7,8-TCDD signal to decline from the LPR into Newark Bay.
- Evaluation of CWCM and Supplemental Sampling Program (SSP) data suggest that Hurricane Irene did not induce a widespread increase of near-surface sediment 2,3,7,8-TCDD concentrations.
- Natural recovery is occurring, though it is inhibited by ongoing internal sources.
- The rate of natural recovery is likely to slow as LPR concentrations reach regional background levels and sediment burial rates decrease.

- Deposition/burial: Deposition and subsequent down-mixing of cleaner solids dilutes contaminants in the surface sediments. Contaminant mass is buried where net deposition occurs.
- Sediment bed processes: Sediment mixing and diffusive processes exchange contaminants between surface and deeper sediments, and influence the net flux to the water column, which in turn may be strongly influenced by the kinetics of sorption processes.

Data analyses and modeling efforts (currently underway) indicate that these processes vary spatially (e.g., by depositional environment, tidal influence), which has implications for long-term transport and short-term dynamics of contaminant concentrations within the estuary. Contaminant fluxes are influenced by the spatial distribution of each contaminant's concentration in surface sediments and its boundary loadings; consequently, net fluxes and local recovery of surface sediments are chemical specific to some degree. Nevertheless, the observation that high surface concentrations of several of the major contaminants tend to be co-located in many areas (e.g., 2,3,7,8-TCDD and PCBs; see Section 3.2 and Figures 3-4a and 3-4b) suggests a similarity of fate, transport, and recovery mechanisms.

Each of these processes is considered in the following section. Section 5.1 discusses tidal transport of solids and reviews contaminant-specific considerations. Section 5.2 considers more generally scour and deposition processes, describing first the flow/tide-dependent transport regimes, followed by a review of sedimentation and sediment stability patterns. Section 5.3 considers the integrated effect of contaminant transport processes on long- and short-term trends. Lastly, Section 5.4 addresses the implications for natural recovery, both qualitatively and quantitatively.

5.1 Estuarine Processes

Freshwater tends to flow on the surface of the water column because it is less dense than the saline water brought into the river by tides and the longitudinal salinity gradient, though turbulence causes partial mixing of these waters. Consequently, there is net upriver flow in the bottom portion of the water column and net downriver flow in the upper portion of the water column. This circulation is known as the estuarine or gravitational circulation.

The location of the salt front varies with the freshwater discharge, inter-tidal timing (spring/neap), and intra-tidal timing (flood/ebb). The salt front location[25] at various river discharges was computed using a hydrodynamic model developed by USEPA Region 2 (see Figure 5-1; HQI 2006). The results indicate that on average, the salt front is situated upriver of RM 5 when discharge at Dundee Dam is below the annual average of 1,200 cfs (HQI 2006; 1,140 cfs at Little Falls). At mean river flow, it can reach RM 7. It is pushed downriver with increasing flow—at 2,000 cfs, it is found on average near RM 3; during a 1-year return flow of 6,000 cfs, it is pushed below RM 2; and during a 5-year return flow of 10,000 cfs, it is pushed below RM 1 (where the river widens). The location of the salt front at a given flow varies with the spring/neap tidal cycle, and can move between 0.5 to 3 miles over the tidal cycle (i.e., the tidal excursion) during neap tides and between 2 and 5 miles during spring tides. Offshore set-up/set-down events[26] also contribute to salt front location variability, though to a lesser degree. Moreover, the simulation results indicate the salt front moving beyond RM 13 under persistent low flows below 200 cfs[27]. The salt front locations shown on Figure 5-1 and summarized previously are shifted somewhat upstream if a lower salinity threshold is used to define the salt front; for example, SEI and HQI (2011) presents a similar figure of model results using a salinity threshold of 0.5 ppt (instead of 2 ppt), which indicates salt front migration above RM 14 under extreme low flow conditions.

The historical salt front migration is qualitatively expected to have been somewhat further upstream than indicated by Figure 5-1, because it reflects model results generated using fairly recent bathymetric conditions (1995 to 2004). Deeper channels in the LPR, as was the case when the navigation channel was maintained at its design depth, would have propagated the salt front farther upstream than under existing conditions by decreasing the bathymetric gradient (assuming similar conditions in Newark Bay). This effect is discussed

[25] For discussion purposes, the location of the salt front is defined here as the location of the 2 parts per thousand isohaline at the bottom of the water column. Figure 5-1 shows the salt front location as a function of the river discharge for a hydrodynamic simulation for water years 1995 to 2004. The time-series of predicted salt front locations was low-pass filtered in order to extract only the response to discharge events (i.e., the daily tidal variability of the results is removed).

[26] Set-up/set-down refers to a rise (and subsequent fall) in mean water levels due to offshore waves. Breaking waves result in a continuous elevated water surface, and larger waves result in increased mean water levels.

[27] Movement beyond RM 13 is not reflected in Figure 5-1 because results were filtered to remove tidal variability.

qualitatively by Chant et al. (2010), and demonstrated via model sensitivity analysis by Cañizares et al. (2009). Persistent low flow conditions, such as the drought that occurred between 1962 and 1966, would cause the salt front to reside farther upstream than under average flow conditions (Chant et al. 2010).

The salt front intrusion and its influence on hydrodynamic and sediment transport conditions are demonstrated on Figure 5-2 using velocity and salinity data and calculated TSS at five stations along the LPR monitored during the fall 2009 PWCM program[28]. These data indicate that under a persistent river flow of approximately 500 cfs, the salt front passed upstream of the RM 10.2 station. During low flow conditions, the horizontal salinity distribution generates a gravitational circulation, enhanced by vertical gradients in the salinity distribution, promoting the displacement of the salt front farther upstream. The data also indicate that within the salt wedge, the flood velocity is larger than the ebb velocity (but the flood period is shorter than the ebb period), which causes net upstream transport of sediment at low river flow within the salt wedge. Upstream of the salt wedge (see RM 13.6 station), ebb currents are larger than flood currents, and although there is some reversal of flow, there is very little variation or pattern to the TSS fluctuations.

The upstream transport associated with tidal resuspension and asymmetrical tidal currents also applies to sediment-bound contaminants, and may generally be thought of as a form of "tidal pumping" (i.e., the temporal correlation of velocity and concentration; Geyer and Nepf 1996). It is an important transport mechanism because it allows, together with the estuarine circulation, solids to migrate upstream from the Lower LPR and Newark Bay, contributing to infilling conditions within the LPR and likely causing some redistribution of the associated contaminants. The prevailing conceptual model is that tidal resuspension primarily involves the mobilization of a distinct "fluff layer" (or "mobile pool") of unconsolidated sediments that overlies a less erodible (consolidated) parent bed. The consolidated bed would only be resuspended if shear stresses increased (i.e., due to a change in the tidal or freshwater

[28] The PWCM program included deployments of moorings to collect in situ Acoustic Doppler Current Profilers (ADCPs); conductivity, temperature, and water depth, and optical backscatter measurements; and collection of grab samples analyzed for suspended solids concentrations (SSC) at five locations along the LPR. The optical backscatter measurements were used to predict a high resolution SSC time series based on a calibration to the concurrently measured SSC grab data.

forcings). Literature support for fluff layer formation is found in, for example, Sanford et al. (1991), Jones et al. (1996), Wang (2003), and El Ganaoui et al. (2004).

Fluctuations in water column suspended solids over the course of a tidal cycle suggest a fluff layer thickness of a few millimeters or less. Some vertical exchange of material between the fluff layer and parent bed must occur over longer timescales[29], but over the course of a single tidal cycle, the reservoir of material available for resuspension is limited to the existing fluff layer unless peak shear stresses increase due to a change in hydrodynamic forcing. Studies suggest that the fluff layer contaminant inventory is replenished from the parent bed via slow exchange processes[30].

5.2 Scour and Deposition

5.2.1 Transport Regimes

The net transport of fine sediment is governed by tidal asymmetry, gravitational circulation, and river flow. At low river flow, tidal asymmetry and gravitational circulation dominate and favor trapping of fine sediments that entered the river over Dundee Dam, from tributaries, or from Newark Bay. At high river flow, river-induced advection dominates, and suspended fine sediments are washed out of the river. At more energetic conditions (very high river runoff, possibly in conjunction with spring tide and rapid set-up/set-down events), scouring of the riverbed at specific locations may be expected. These regimes can be depicted conceptually (see Figure 5-3) and are defined as follows:

1. Regime 1 – Low river flow (low energy conditions) during which fine sediments are trapped in the river, partly in the river's turbidity maximum, partly through settling elsewhere on the riverbed: During extended periods of low river flow, there is a net upstream movement of sediments from Newark Bay into the LPR and a net infilling of the LPR. The upriver extent of solids transport and infilling are functions of freshwater inflow and tidal range.

[29] For example, consolidation and organism uptake/defecation of sediment would move material downward into the parent bed, and physical disturbances due to organism activity would induce mixing at the interface.

[30] The contaminant inventory of the fluff layer would be replenished by particle mixing and a flux of dissolved or colloidal contaminant due to a number of processes that are typically lumped together and treated as a diffusive porewater exchange.

2. Regime 2 – Moderate river flow (medium energy conditions) during which fine sediments that had accumulated in the water column (turbidity maximum) or a fluffy layer of unconsolidated fine sediments on the bed are flushed out of the river into Newark Bay: It is expected that under these conditions the sediment bed generally remains stable.
3. Regime 3 – High river flow (high energy conditions, possibly in conjunction with spring tide or rapid set-up/set-down) during which the riverbed may scour at specific locations: Sediments transported into the LPR during high flow conditions are either transported through the system (fine-grained sediments) to Newark Bay or deposited within the LPR (coarse-grained sediments), depending on flows and tidal range.

The contaminant concentrations on resuspended particles are expected to transition from being primarily representative of a distinct fluff layer in Regime 1 to being primarily representative of the near-surface parent bed in Regime 3, reflecting the associated deeper scour. As discussed in Section 5.3, analysis of the CWCM data is ongoing to better understand variations in resuspended contaminant concentrations and the associated fate and transport implications.

The PWCM data collected during fall 2009 were used to characterize the transition between Regimes 1 and 2 (see Figure 5-4). Positive fluxes indicate upstream transport and negative fluxes indicate downstream transport. At upriver locations (RM 13.5 and RM 10.2), the estimated net daily flux for this period is predominantly downstream; at downriver locations (RM 6.7, RM 4.2, and RM 1.4), the net flux is directed upriver at low flows and downriver as flows increase. The transition between upriver and downriver solids transport at RM 1.4 occurs at about 2,000 cfs (at Little Falls), although the transition is location dependent (the flow threshold decreases moving upstream). For reference, Chant et al. (2010) estimated the transition upstream and downstream net daily transport at RM 3 to occur around 1,100 cfs. USEPA (SEI and HQI 2011) estimates a transition at about 700 cfs based on data from the RM 3 to RM 4.2 interval, which implies upstream transport approximately 50 percent of the time in that region.

During and following periods of navigation channel maintenance (see Figure 2-5), the picture in the top panel of Figure 5-3 was quantitatively different because flow velocities in the river were substantially smaller because of the larger river depth (river cross-sections). The transitions between the various regimes, and also the full-flushing conditions, would shift to the right as sketched in the bottom panel of Figure 5-3. This explains why sedimentation rates in the post-dredging period (i.e., after 1950 in the lower 8 miles) were higher than today because sedimentation-favorable conditions were more frequent, and scouring-favorable conditions were less frequent.

The volume of sediment deposited in the lower 6 miles of the LPR is similar to the estimated solids load to the system in the past 60 years (as estimated by Chant et al. 2010), suggesting that the LPR has been a highly efficient sediment trap and that solids from Newark Bay have contributed. Recent data indicate ongoing solids exchange with Newark Bay. This is illustrated by Figure 5-5, which shows LPR flux calculations for a period in 2008/2009, during which Chant collected mooring data at RM 1.4, and captures many of the dynamics previously discussed. The middle panel of this figure shows the estimated[31] solids loading (black line) at Dundee Dam; cumulative load (red line) increases monotonically and reflects a sharp increase during the mid-December high flow event (note the log scale). The bottom panel shows flux calculations using data at RM 1.4 for the same period, where the daily net flux is shown along with the gross flood tide and ebb tide fluxes. During the low to moderate flow period (September through November 2008), the daily net flux (black line) is mostly upstream (positive), which yields a cumulative upstream load. The high flow event in December causes a net flux in the downstream direction, flipping the cumulative load to downstream. The net flux eventually turns upstream such that the cumulative load begins to decrease slowly. The back and forth sediment exchange with Newark Bay is suggested by the gross fluxes on flood and ebb tide (dashed lines), indicating spring/neap tide variability but with the flood tide generally being greater due to tidal asymmetry. Although the magnitude of the flux is small relative to high flow transport (consistent with the notion that low flow tidal resuspension is only on the order of millimeters [SEI and HQI 2011]), the net upstream flux occurs throughout most of this period, illustrating that solids exchange with Newark Bay is common[32]. Once in the river, these solids can settle and mix with LPR solids, and be subject to redistribution by subsequent tidal currents or high flow events. Thus, there

[31] This is estimated using a flow-solids loading relationship (SEI and HQI 2011).
[32] In its calculation of solids flux passing through the region around RM 3 to RM 4.2 in the 1994 to 2010 interval, USEPA estimated that net upstream transport would occur 50 percent of the time (SEI and HQI 2011).

is mixing of LPR and Newark Bay solids and, in that sense, they both act as solids sources to each other depending on the flow/tide conditions.

5.2.2 Sedimentation

The LPR has been an efficient sediment trap (Chant et al. 2010), though trapping efficiency has been dropping as the river moves toward a relatively stable cross-section that reflects a rough balance between alternating deposition and erosion of surface sediments[33].

Sedimentation rates determined from downcore radiochemical profiles (Cs-137 and Lead-210 [Pb-210]) in LRC cores correspond well to the dredging history of the river (summarized on Figure 2-5). Higher net sedimentation rates were observed in the lower 7 miles and within the limits of the navigation channel that was maintained until approximately 1949, with the highest rates occurring downstream of RM 1 where dredging occurred as recently as 1983. Net sedimentation rates below RM 7 averaged 0.12 foot per year (3.7 cm per year), and varied from 0.02 to 0.55 foot per year (0.6 to 16.8 cm per year; see Figure 5-6). Above RM 7, where there was more spatially and temporally sporadic historical dredging, net sedimentation rates were notably lower; the average sedimentation rate was 0.05 foot per year (1.5 cm per year), and the range was 0.01 to 0.23 foot per year (0.3 to 7.0 cm per year).

Sedimentation rates are related to the geomorphology of the river. For example, sedimentation rates estimated from cores collected from the outer bends, point bars, and in higher velocity reaches of the river generally were lower than those observed in cores within the main channel or from inner bends. At several locations in the river (e.g., RM 0.5, RM 7.3, and RM 10.9), point bars or mud flats had low net sedimentation rates, although sedimentation rates were likely higher during their formation. The cores at these locations generally exhibited well-behaved Cs-137 profiles, consistent with the depositional and geomorphically stable characteristics of point bars. The intact, buried Cs-137 peaks indicate that these areas have been subject to low rates of deposition and suggest that these locations were never dredged or significantly eroded during extreme flow events.

[33] The slowing of deposition rates may be offset to some extent by future sea-level rise.

At locations with low sedimentation, peak contaminant concentrations are generally at or near the sediment surface, as observed on some of the mudflats above RM 7. A plot of surficial contaminant concentrations versus sedimentation rate (see Figure 5-7) shows that, for all contaminants evaluated, the highest surficial concentrations are found at the locations with low sedimentation rates. These locations are still subject to recovery due to the dilution associated with deposition and down-mixing of cleaner sediments and episodic erosion that roughly balances the deposition, though recovery rates are lower than where dilution is coupled with burial.

5.2.3 Sediment Stability

Sediment stability in the LPR has been examined by evaluating and integrating multiple lines of evidence, including downcore radiochemical profiles, downcore contaminant profiles, and bathymetric changes.

5.2.3.1 Radiochemical Profiles

Cs-137 data in cores collected during the LRC program suggest a spatial pattern to their vertical profiles. Most cores between RM 1 and RM 7 showed evidence of a peak at depth, suggesting burial (the peak is indicative of the approximate 1963 sediment horizon, the year of peak Cs-137 use; see Figure 5-8). Cs-137 profiles generally were not datable between RM 0 to RM 1 because the Cs-137 profiles showed no pattern with depth. This is consistent with the relatively recent dredging activities that eliminated the 1954 and 1963 dating markers from the sediment bed. Upstream of RM 7, cores with buried peaks are interspersed with cores that could not be dated. Cores without an intact Cs-137 profile were observed at locations without deposition due to higher channel velocities (e.g., just below Dundee Dam) or locations with a stable sediment bed with low deposition. The relatively coarse segmentation of the sediment cores obscured the pattern of Cs-137 deposition in the latter (cores were sectioned at 6 inches below the core top and in 1- or 2-foot increments for the rest of the core). The presence of the well-behaved Cs-137 profiles over much of the lower river and in the navigation channel indicates that the sediment bed is stable at these locations. Deep erosion is uncommon, and typically sediments deposited in the 1950s and 1960s have remained stable.

Peak Cs-137 concentrations were observed at or near the sediment surface (see Figure 5-9) at several mudflat locations upstream of RM 7, again suggesting either a stable sediment bed with slowed or ceased sedimentation, or erosion that exposed buried sediments. The low energy environment at these locations (inner bends where water velocities and associated shear stresses are expected to be generally below river averages) precludes erosion as the reason. This suggests that the deposition that formed the mudflat has slowed or ceased, leaving 1960s' sediment at or near the surface. This corresponds well with the high surficial contaminant concentrations observed in the mudflats (as observed in Section 3.2)—2,3,7,8-TCDD concentrations (OC-normalized) are highest in the RM 10.9 mudflat[34], as are many other contaminants.

5.2.3.2 Contaminant Profiles

The contaminants with peak loadings in the 1950s and 1960s (see Sections 2.2 and 3.2.1) are expected to exhibit a distribution similar to that of Cs-137, with a peak buried below the sediment surface. Vertical profiles of Cs-137 and contaminants show that the peak contaminant concentrations in each sediment core tend to be buried below the surface and approximately collocated with the peak Cs-137 concentration (see Figure 5-10). Comparison of the depth of the peak contaminant concentrations with the depth of the peak Cs-137 concentration in the sediment bed shows that the peak contaminant concentrations frequently occur at or below the peak Cs-137 concentration, indicating that peak chemical concentrations were deposited before or around 1963, and have remained generally stable in the sediment bed for more than 50 years. It must be noted that the converse is not necessarily true; cores without distinct Cs-137 peaks and/or Cs-137 and collocated contaminant peaks may still be stable. For example, sediments in RM 0 and RM 1 do not have well-defined Cs-137 profiles because of the more recent dredging activities, as discussed previously, but contaminant concentrations appear to be stable within the sediment bed, based on the Pb-210 profiles that indicated consistent net deposition.

[34] The highest dry weight 2,3,7,8-TCDD surface concentration was observed near RM 7.5.

5.2.3.3 Bathymetry Data

Bathymetry data from 1949, 1966, 1995, 2007, 2008, 2010, 2011, and 2012 were evaluated to identify areas that have been net depositional, net erosional, or subject to cyclic erosion/deposition. Historical bathymetry data (1949 and 1966) were compared to recent data in a qualitative manner[35] to characterize net changes in the sediment bed. Recent bathymetry data were evaluated for erosional and depositional patterns observed between surveys. The following patterns were evident in the depth difference maps:

- The navigation channel between RM 2 to RM 7 (where the 1949 and 1966 bathymetry data were collected) has been largely net depositional with sedimentation ranging from 0 to more than 10 feet.
- Some areas were net depositional prior to the mid-1990s but were net erosional between 1995 and 2010—perhaps reflecting the frequent high flow events that occurred post-1995.
- There are large areas of the sediment bed where no change is observed between the series of recent surveys, indicating a stable bottom.
- There is no change in elevation in the mud flat areas and at the edges of the river at the extent of the survey.
- There are limited areas subject to significant erosion between the 2010 survey and the 2011 survey, presumably reflecting the passage of Hurricane Irene in between.
- There are areas where cyclic patterns of erosion and deposition occur in response to high flow events and subsequent periods of low flows.

A comparison of the 1949 and the 2010 bathymetry data (see Figure 5-11) roughly characterizes the historical deposition within the navigation channel between RM 2.5 and RM 6.8 (where historical bathymetry data were collected). Approximately 50 percent of the sediment bed in this area experienced high (greater than approximately 7 feet) deposition over this period, presumably resulting from the cessation of dredging. The highest historical deposition was observed generally on inner bends and below RM 4.6. Little or no historical

[35] Historical bathymetry surveys provide point measurements that include uncertainty in both horizontal positioning and depth, and additional uncertainly is introduced when these data are digitized and interpolated to develop bathymetric surfaces for temporal comparisons. The uncertainty in the historical data limits the ability to develop quantitative comparisons with recent bathymetry data.

deposition was observed along outer river bends and above RM 5.5, where higher flow velocities are observed. The extensive net deposition observed over much of this reach is an indication of a stable sediment bed (consistent with the radiochemical and contaminant profiles described previously).

Areas that exhibit little or moderate net historical deposition (less than approximately 7 feet) were further evaluated to better characterize the observed patterns and present-day depositional conditions. Some of these areas were net erosional between 1995 and 2012 (based on differences between the 1995 and 2012 bathymetric data of greater than 1 foot of erosion). They are primarily located on the outer bends, where channel velocities and associated shear stresses are expected to be higher than the average velocities (see Figure 5-11). The transition from net deposition (based on changes relative to the 1949 condition) to net erosion (based on changes between 1995 and 2012) was perhaps due to the more frequent high flow events that occurred in the later period (the daily average flow at Little Falls exceeded 13,000 cfs [the 10-year flood] twice in the 47 years from 1949 to 1995 and six times in the 16 years from 1996 to 2011).

A series of depth difference maps were developed using the recent sequential multibeam bathymetric surveys, which cover predominantly low flow periods (2007 to 2008 and 2011 to 2012) and periods with high flow events (2008 to 2010 and 2010 to 2011, the latter of which includes the passage of Hurricane Irene, a greater than 50-year flow event; see Figure 5-12 for 2007 to 2012 hydrograph). The maps show large areas with little or no net change over much of the LPR (see Figures 5-13a through 5-13f). The depth difference map between June 2010 and October 2011 (post-Hurricane Irene) indicates areas of both erosion and deposition following the hurricane; however, the extent of the erosion was somewhat limited and the depth of erosion relatively shallow in most areas, confirming the stability of the sediment bed. The persistent low flow conditions following Hurricane Irene were associated with widespread infilling that extended up to RM 13 (evidenced in the depth difference map between October 2012 and October 2011). The infilling pattern suggests the importance of upstream solids movement during low flow conditions.

In many areas, such as the lower 0.5 mile of the navigation channel, small-scale erosion and deposition observed in many areas of the LPRSA occurs in a cyclic or alternating pattern, where erosion apparent after high flow events is followed by deposition during low flow periods or vice versa (erosion is observed following a low flow period and deposition following a high flow event; see Figures 5-13a through 5-13f). Other areas where this cyclic behavior was observed include below the NJ Turnpike Bridge at RM 2.4 and within the bend at RM 3.7 (see Figure 5-14). The latter area may experience cyclic erosion/deposition due to the proximity to the irregular shoreline along the north bank. Although the specific causes of this cyclic pattern may differ in each area, there is no significant net erosion or deposition in these areas, consistent with the dynamic equilibrium of the river.

5.3 Contaminant Fate and Transport

The Diamond Alkali pesticide manufacturing facility at 80 and 120 Lister Avenue, in Newark, NJ, is widely documented as the predominant source of the 2,3,7,8-TCDD in the LPRSA, and analysis of recent datasets supports this presumption (see Appendix B). As such, the 2,3,7,8-TCDD patterns in the river provide a means to infer transport patterns.

5.3.1 Long-Term Contaminant Fate and Transport

Figure 5-15 displays the longitudinal distributions of the core-maximum, OC-normalized 2,3,7,8-TCDD concentration (top panel[36]) and the estimated 2,3,7,8-TCDD mass inventory[37] (bottom panel). Taken as a whole, the distributions on Figure 5-15 indicate that transport mechanisms have dispersed 2,3,7,8-TCDD approximately 11 miles upstream of the source at RM 3.2 to approximately RM 14 and at least 8 miles downstream across Newark Bay[38]. They

[36] A linear scale is used in this case to better highlight the dramatic gradients of 2,3,7,8-TCDD in the system. An alternate version of this figure using a logarithmic scale may be found in Appendix B (see Figure B-6).

[37] The bars indicate the mass inventory in each spatial bin, referencing the left-hand axis. The dashed blue line indicates the total mass integrated longitudinally from Dundee Dam moving downstream, referencing the right-hand axis (i.e., the blue line shows the summation of the bars moving from left to right). The mass estimate was constructed using Thiessen polygons delineated for "complete cores" only (see Section B.2 for further details). The interpolated dataset differs somewhat from the one used in the top panel of Figure 5-15, in that the 1995 and 2012 TSI FSI core datasets are included to better constrain the mass interpolation. The 1995 dataset was excluded from the top panel in order to maintain consistency with other concentration figures in this report, but conclusions regarding the trends in mean peak 2,3,7,8-TCDD concentration are not strongly influenced by this choice. The 2012 TSI FSI dataset does not appear in the top panel due to the absence of organic carbon data.

[38] The extent of influence is also supported by the longitudinal distribution of the fingerprint ratio of 2,3,7,8-TCDD to total TCDD (see Appendix B).

also indicate that the lower miles of the LPR and Upper Newark Bay have historically been an effective trap of contaminants. Approximately 76 percent (27 kilograms [kg]) of the 2,3,7,8-TCDD inventory in the LPR and Newark Bay was estimated to reside in the lower 6 miles, of which 57 percent (20 kg) resides within about 1 mile of the Lister Avenue Site source (i.e., the RM 2 to RM 4 bin[39]). Another important feature is the lack of longitudinal gradients in the maximum concentration (see Figure 5-15 [top panel]) within the 2-mile bins of the lower 14 miles of the LPR. The mean peak concentrations are lower moving away from the RM 2 to RM 4 bin but are fairly well-distributed throughout the lower 14 miles of the LPR (within a factor of 5 of the RM 2 to RM 4 bin), despite the strong source indicated by the sediments within the Lister Avenue Site Phase 1 footprint (two orders of magnitude higher; see Figure 2-4 for a map of this area). This dampening of the source signal is attributed to sediment redistribution associated with estuarine transport processes.

The data also suggest that the net downstream flux of 2,3,7,8-TCDD from the source has historically exceeded the net upstream flux (see Figure 5-15 [bottom panel]). Approximately 18 percent (6.6 kg) of the LPR/Newark Bay 2,3,7,8-TCDD mass is estimated to reside upstream of RM 4, compared to 25 percent downstream of RM 2 (8.8 kg). The skewed mass distribution[40] on Figure 5-15 (bottom panel) suggests that the net upstream contaminant transport processes that are expected during low to moderate flows within the salt wedge have historically been dominated by local trapping near the source and the net downstream transport that is expected during elevated flow regimes (based on sediment transport considerations; see Sections 5.1 and 5.2; also Chant et al. 2010). Although the inferred downstream skew in the 2,3,7,8-TCDD mass distribution is influenced by factors such as historical navigation channel dredging (analyses currently ongoing) and unaccounted mass in the other Newark Bay tributaries (i.e., the Hackensack River and the Kills), it is expected that

[39] The estimates provided herein do not account for mass removal from the Phase 1 footprint area in 2012. The mass inventory within that footprint was estimated to be approximately 6 kg.

[40] The slight downstream skew persisted in an interpolation sensitivity in which the channel and shoals were interpolated separately (62 percent of the mass for the RM 2 to RM 4 bin, with 18 percent upstream of RM 4 and 20 percent downstream of RM 2). This sensitivity is considered less credible due to data density concerns (e.g., an extended longitudinal influence of cores from within the Phase 1 footprint).

these factors would tend to further enhance the downstream skew[41]. The consistency of the patterns in Figure 5-15 with sediment transport processes is considered below, given the hydrophobic nature of 2,3,7,8-TCDD.

The 2,3,7,8-TCDD distribution upstream of RM 4, which includes a decline in the mass inventory moving upstream[42] and an effective net upstream transport limit of approximately RM 14 (see Figure 5-15), is qualitatively consistent with both a declining contaminant transport potential moving upstream and a declining trapping potential. The possible influence of upstream dredging in the post-Lister Avenue Site discharge era (1970s; see Figure 2-4) is not considered here given it impacted only the channel and constituted only a portion of the channel area in most stretches (analysis currently undergoing). The major upstream transport modes (estuarine circulation and tidal pumping) are expected to vary moving upstream and eventually decay at the salt front[43]. Figure 5-16 suggests an approximate[44] intrusion frequency of less than 5 percent for RM 12 and less than 1 percent for RM 14 (though these probabilities were likely somewhat higher during the time of peak

[41] The estimated 2,3,7,8-TCDD mass inventory downstream of RM 2 does not account for all discharged mass, in that it excludes 1) mass removal associated with navigation channel dredging in the lower 2 miles of the LPR (see Figure 2-5) and in Newark Bay after the cessation of the Lister Avenue Site discharge in 1969; and 2) mass lost to the Kills and to the Hackensack River. By comparison, the possible under-estimate of mass inventory in the LPR above RM 4 due to navigation channel dredging is likely less given the expected smaller dredge volumes; only distinct portions of the channel above RM 7.9 were partially dredged as part of a project in the 1970s (see Figure 2-5; about 3.1 miles in total), and the channel is narrower with less historical infilling.

[42] The present focus is on the large-scale trend of declining mass upstream of RM 4, which is monotonic with the exception of the RM 8 to RM 10 bin. Local differences in long-term trapping potential could give rise to a non-monotonic pattern, but it is more likely a consequence of lower core density in this reach (six cores) given its smaller cross-sectional area, dredging history, and lower average fine sediment fraction.

[43] The salt front marks the limit of the net landward bottom flow associated with the estuarine circulation and the stratification that induces the flood-dominant tidal asymmetry (e.g., Dronkers 1986; Burchard and Baumert 1998).

[44] The estimated salt front intrusion frequencies in Figure 5-16 are approximate in nature and for discussion purposes only. Flow relationships from Chant et al. (2010), Cooperating Parties Group (CPG) model results (regression of values in Figure 5-1), and SEI and HQI 2011 (visual inspection of figure therein) were used to estimate flows at which the 2 ppt or 0.5 ppt isohalines could reach the segment boundaries considered in Figure 5-15. The flows were converted into cumulative frequencies using the historical flow record at Little Falls. Also shown are the observed frequencies of 0.5 ppt and 2 ppt in the maximum daily salinity record at five PWCM moorings.

2,3,7,8-TCDD loading when less infilling had occurred in the lower river[45]). A decreasing trapping potential moving upstream of RM 8 is indicated by the generally decreasing prevalence of fine-grained deposits, especially above RM 14 (see side scan sonar on Figure 2-3). Likewise, there is a decrease of average surficial fine sediment fraction with distance upstream, most notably within the navigation channel (see Figure 5-17). The trend suggests that fine material (and associated contaminants) deposited during low flows is more likely to be scoured during high flows from the navigation channel than from outside of it and more so in the upper LPR than in the lower reaches, consistent with expected high flow shear stress trends moving downstream (the depth and cross-sectional area increase downstream, particularly below RM 8; see Section 2). It is noted that these inferred transport and trapping potentials are unlikely to be independent of each other; the upstream processes that delivered 2,3,7,8-TCDD to the upper LPR are presumably also critical in the upstream delivery of fine solids and the regulation of a "mobile pool" (Geyer 1993).

Likewise, the 2,3,7,8-TCDD distribution downstream of RM 2 reflects transport and trapping potentials, although the arguments are complicated by the confounding effect of more extensive navigation channel dredging in this region. Relative to upstream, generally more favorable trapping conditions exist in the expanded cross-sections of the Lower LPR and Upper Newark Bay (as indicated by the increasing net sedimentation rates and fine sediment fractions moving downstream, and the historical infilling of the navigation channels downstream of RM 2 and in the northwestern section of Newark Bay; see Figure 2-5; USACE 2010; Sommerfield and Chant 2010). Regarding transport potential, the declining influence of 2,3,7,8-TCDD from the LPR with distance downstream[46] is consistent with a settling and solids mixing signature, and more specifically with the following two solids transport considerations. First, the probability of a hydrologic event capable of delivering significant amounts of LPR solids to a given location should generally decrease moving across Newark Bay, notwithstanding the complexities of circulation and sediment transport responses to the

[45] See Chant et al. (2010) for the supporting scaling arguments for this bathymetry effect, which has also been confirmed via hydrodynamic simulation (Cañizares et al. 2009).
[46] This is indicated by the declining trend in maximum concentration (see Figure 5-15 [top panel]), in mass inventory (see Figure 5-15 [bottom panel]), and in the fingerprint ratio of 2,3,7,8-TCDD to total TCDD (see Appendix B, Figure B-4 [top panel]). These declining trends are likely enhanced by the navigation channel dredging within Newark Bay, particularly in the case of estimated mass inventory.

freshwater flow, wind, and tidal forcings (Chant 2006; Pecchioli et al. 2006; Pence et al. 2005; Wakeman et al. 2007; Sommerfield and Chant 2010). Episodic high flow events likely contribute to more widespread transport of LPR sediments in Newark Bay than occurs under typical conditions. Second, under most conditions, there is a net northward (landward) solids transport along the navigation channel in Newark Bay toward the LPR and the Hackensack River due to a combination of tidal pumping and gravitational circulation; and even during high flow events settling, LPR solids may be transported by the intensified net northward near-bottom flow (see Chant 2006; Pecchioli et al. 2006; Sommerfield and Chant 2010)[47]. The above processes imply that, moving across Newark Bay, the sediment bed reflects a declining fraction of solids originating from the LPR, which is consistent with the mean longitudinal concentration trend. Nonetheless, the longitudinal trend may also be influenced by other factors that give rise to localized differences in deposition patterns throughout Newark Bay, as well as navigation channel dredging. Additional effects that may influence patterns within the LPR as Newark Bay is approached include the following:

- Volumetric dilution of contaminant and TSS concentrations, favoring a higher equilibrium dissolved fraction
- Transfer of contaminant mass from LPR solids to solids originating elsewhere (e.g., Newark Bay, the Kills, the Hackensack River)
- Enhanced sorption to solids due to higher salinity (e.g., Uncles et al. 1988)

However, these water column effects seem less likely to exert a strong influence on the mean longitudinal trend given the expected slow desorption of 2,3,7,8-TCDD (see Section 5.3.2.1).

5.3.2 Short-Term Contaminant Fate and Transport

The CWCM program was designed to capture water column contaminant concentrations under different flow and tidal conditions (see overview in Section 3.2). As of July 2013, there are six CWCM sampling events for which validated data are available: August 2011,

[47] The circulation patterns and associated longitudinal mixing of solids along the channel may partially explain the apparent faster decline in the influence of LPR solids within the navigation channel than outside it (as inferred from the ratio of 2,3,7,8-TCDD to total TCDD on Figure B-4). However, the differences in these trends is likely magnified by the navigation dredging downstream of RM 2 in the post-Lister Avenue Site era.

February 2012, March 2012, June 2012, August 2012, and December 2012. These events (see Table 3-2) were characterized by low to moderate freshwater flows (165 to 3,090 cfs at Dundee Dam) under a variety of tidal conditions (mean tidal ranges from 3.9 to 6.7 feet at Bergen Point, covering both neap and spring tides). An overview of the results is provided on Figure 5-18, which summarizes the distribution of the 2,3,7,8-TCDD water column response in terms of the event-mean freshwater flow (see Figure 5-19 [left panel]) and event-mean tidal range (see Figure 5-18 [right panel]) for stations within the LPR only. Consistent with the preceding section, focus is primarily directed at 2,3,7,8-TCDD in subsequent discussions.

5.3.2.1 Water Column Concentration Relationships within the LPR

For a given sampling event, water column contaminant concentrations in the LPR exhibit a wide range spanning several orders of magnitude, suggesting that there are strong temporal and spatial fluctuations driven by localized combinations of shear stress (as a response to flow, tidal forcing, and local geometry) and surface sediment contaminant concentrations. As expected from aforementioned hydrodynamic and sediment transport considerations, there is some indication that the freshwater flow influences the median and range of 2,3,7,8-TCDD concentrations within the LPR (see Figure 5-18 [left panel]; higher 2,3,7,8-TCDD concentrations occurred during the events with flows in excess of 1,200 cfs), although a similarly global influence of the event-mean tidal forcing is not apparent (see Figure 5-18 [right panel]). Sampling station-specific responses, including analysis of water column dynamics above and below the salt front, will be included in future updates to this document.

LPR water column 2,3,7,8-TCDD concentrations show a strong correlation with TSS, indicating that the particulate phase dominates the water column distribution (see Figure 3-7). This likely occurs because the water column response reflects the resuspension of local sediments whose 2,3,7,8-TCDD does not desorb because the desorption timescale is long relative to the settling timescale of the resuspended particles. 2,3,7,8-TCDD desorption timescales are on the order of days to months (Sormunen et al. 2009), whereas the settling time of the silt particles expected to dominate the intra-tidal variability in suspended solids are on the order of a few hours (assuming a settling of 1 millimeter per second).

The inferred dominance of the particulate phase in the water column allows water column particulate concentrations to be compared to sediment concentrations to assess the nature of the water column response. A spatial comparison of inferred water column particulate concentrations (i.e., total concentration normalized by TSS) and surface sediment (0- to 6-inch) concentrations is presented on Figure 5-19, where the floating CWCM stations have been grouped with the closest static CWCM station[48] and the post-2000 sediment dataset has been averaged into bins that are longitudinally centered on the CWCM station locations and the edge of the bins corresponds to the mid-point between CWCM stations. The data on Figure 5-19 have also been grouped into low flow (left panel) and moderate flow (right panel) sampling events[49]. Within the LPR[50], the following two main observations stand out:

1. 2,3,7,8-TCDD along river water column concentration trends are similar to those of the surface sediments (analysis ongoing), consistent with the notion that the water column reflects a localized sediment resuspension response (e.g., within a tidal excursion).
2. The inferred water column particulate concentrations are substantially lower than the average 0- to 6-inch surface sediment concentrations.

[48] On Figure 5-20, post-2000 surface sediment data are grouped with the closest static CWCM station location. CWCM floating station samples and corresponding sediment data are grouped at RM 6.7 and RM 4.2. Furthermore, the sediment data are grouped into all areas (top panel), as well as shoal (middle panel) and non-shoal (bottom panel) areas to compare more localized parent-bed concentrations relative to the water column data. It is noted that RM 6.7 and RM 4.2 are where the two floating stations were held static during the August 2011 sampling event. More details on the location variation in CWCM floating stations TTR1 and TTR2 can be found in the CWCM Quality Assurance Project Plan (AECOM 2011b).

[49] The "low flow" (left panel) and "moderate flow" (right panel) groupings on Figure 5-19 are qualitative and applied here for discussion purposes. The "low flow" data comprise the February, March, August, and December 2012 CWCM events, for which the event mean flows were 688, 392, 247, and 557 cfs, respectively. The "moderate flow" data comprise the August 2011 and June 2012 CWCM events, for which the event mean flows were 2,448 and 1,249 cfs, respectively.

[50] Within Newark Bay, there is greater scatter in the relationship between contaminant concentration and TSS, presumably reflecting a greater mixing of solids from different origins (i.e., the LPR, the other Newark Bay tributaries, and locally resuspended sediments). Mean water column concentration also appear closer to the mean bed concentrations in Newark Bay than in the LPR, although detection limits influence the comparison for 2,3,7,8-TCDD in particular. The contaminant exchange between the LPR and Newark Bay is under investigation as part of the development of the RI/FS contaminant fate and transport model, and will be addressed in future updates.

The latter conclusion appears to hold even if the sediment data are averaged separately for shoal and non-shoal areas or if the water column data are segregated into low and moderate flow regimes (see Figure 5-19). Analyzing the water column and sediment spatial pairs for shoal and non-shoal areas during both low and moderate flows for RM 0 to RM 8 (i.e., the pairs shown on Figure 5-19) yields that water column particulate concentrations are, on average, approximately 10 to 40 percent of the 0- to 6-inch average sediment concentrations.

The discrepancy between inferred water column particulate concentrations and the average 0-to 6-inch sediment concentrations within the LPR is thought to be mainly attributable to vertical gradients over the top 6 inches of sediments, and likely reflects a steep concentration between the parent bed and an overlying millimeter-scale, un-consolidated fluff layer. As discussed in Section 5.1, contaminant exchange processes between the parent bed and the fluff layer are expected to be slow relative to the time between tidal resuspension events, meaning that equilibration between fluff layer and parent bed concentrations would generally not be expected to occur. The discrepancy between bed and water column concentration s would be expected to be less during high flows, to the extent that parent bed scour also occurs. The accuracy of this conceptual model of the influence of vertical concentration gradients[51] is under investigation as part of the RI/FS contaminant fate and transport model development, which includes further analysis of the CWCM dataset.

5.3.2.2 High Flow Contaminant Transport

Data from the CWCM program high flow events have recently been collected, thus filling a substantial data gap in characterizing contaminant dynamics during elevated freshwater flows, including peak water column concentrations and impacts on LPR contaminant export. Analyses of these data are ongoing and will be included in future updates to this document.

[51] Other plausible explanations for the inferred discrepancy between bed and water column particulate concentrations within the LPR include 1) tidal resuspension is dominated by solids flux from local areas with lower concentration sediments; or 2) the water column data reflect lower concentration solids not originating from the locally resuspended sediment (i.e., beyond a tidal excursion), possibly leading to a dilution of particulate concentration.

A related but equally central question pertaining to high flow contaminant dynamics is the extent to which such events alter surface sediment contaminant concentrations by exposing more contaminated sediments at depth, potentially impacting the water column response and the exposure concentrations of biota. As discussed in Section 5.2.3.3, a comparison of multibeam bathymetric datasets suggests that the bed is generally stable in that areas of substantial scour were fairly limited during an extreme event such as Hurricane Irene (which occurred in late August 2011 and yielded freshwater flow rates of up to 24,700 cfs at Dundee Dam; see Section 5.2). The available datasets only allow for a crude assessment of the impact of Hurricane Irene to levels in the bed and water column, which is included here in the absence of more definitive high flow contaminant data at this time. The first dataset of relevance is the Supplemental Sampling Program (SSP), which was collected in winter 2012 and captured several sediment cores with elevated surface 2,3,7,8-TCDD concentration including six in excess of 2,600 nanograms per kg[52] between RM 1 and RM 7. A direct assessment of Hurricane Irene-induced changes is not possible given the limited overlap with prior sampling programs. However, it is noted that only one of these cores coincided with areas of deep scour as inferred from pre- and post-Hurricane Irene multibeam bathymetric surveys, and the remainder was better correlated with longer term bathymetric changes from the period 1995 to 2012, where elevated surficial contaminant concentrations were associated with erosional areas. Given that one design objective of the SSP program was to fill data gaps in areas of suspected high concentrations, coupled with the above observation of scour patterns, the SSP data do not generally suggest a widespread increase in surface concentration due to Hurricane Irene. A confounding factor to this interpretation is the low flow period that preceded the SSP data collection, during which sediment infilling conditions prevailed.

The second dataset of relevance to assessing the possible impact of Hurricane Irene on surface sediment concentrations is the CWCM program. The August 2011 sampling event was conducted 1 week before Hurricane Irene, and subsequent sampling events were conducted in February, March, and June of 2012. There is no indication of a systematic shift

[52] These cores resulted in a mean RM 1 to RM 7 surface concentration that was higher than other recent datasets, including the LRC and Field Sampling Plan Volume 2 programs. RM 1 to RM 7 is focused on here because it is the region in which recovery trends were estimated (see Section 5.4).

in water column concentrations between the pre- and post-Hurricane Irene events, although the interpretation is confounded by differences in the prevailing flow and tidal forcings between the events (August 2011 sampled the highest flow of any event to date). Another confounding factor is that the 2012 events did not occur until 5 months or more after Hurricane Irene, during which substantial low flow infilling may have occurred. The caveats associated with these interpretations emphasize the utility of the recently completed high flow sampling in better characterizing high flow contaminant dynamics in the LPR.

5.4 Natural Recovery

The contaminant concentrations on LPR surface sediments reflect historical and ongoing contaminant loadings, solids loading, sediment and contaminant transport processes, infilling, high flow events, human activity, etc. The decline of those concentrations (and reductions in tissue concentrations) as a result of natural processes is termed natural recovery.

5.4.1 Conceptual Model of Natural Recovery

Natural recovery occurs because of several processes that cause contaminant concentrations in the surface sediment layer to decline. Deposition introduces particles that typically have a lower concentration than in the surface layer largely because the major sources of new particles are the watershed above Dundee Dam and Newark Bay, which typically exhibit lower concentrations for many contaminants than are found in the LPR surface sediments. These particles are mixed into the surface sediments (i.e., down-mixed) and reduce concentration by dilution. Sedimentation, which occurs if deposition exceeds erosion, reduces concentration by burying the higher concentrations present in the layer and particularly near the bottom of the layer. Tidal resuspension of fluff layer contaminants to the water column provides an additional loss mechanism, although the impact of this flux on recovery may be nominal under normal tidal conditions given the slow exchange processes thought to transfer contaminants from the parent bed (e.g., diffusion). Likewise, diffusion to the water column from sediment porewater is typically considered a minor factor in surface sediment recovery.

5.4.2 Natural Recovery Patterns

The highest contaminant concentrations are typically found below the surface sediments, demonstrating recovery since the periods of highest loading. For example, below RM 12, 2,3,7,8-TCDD peak concentrations (see Figure 5-15, top panel) are about three to thirty-six times higher than the surface concentration averages (see Figure 3-3a). However, the data also indicate that the rate of recovery has not been spatially uniform. The longitudinal distribution of the average surface 2,3,7,8-TCDD concentration differs markedly from the distribution of the average peak concentration, with the average surface concentration cresting in the RM 10 to RM 12 reach rather than near the Lister Avenue Site at RM 3. The longitudinal gradient reflects the fact that net sedimentation has generally been higher in the lower 6 miles of the LPR.

Building on the previously noted correlation between contaminant surface concentration and net sedimentation rate (see Section 5.2.2 and Figure 5-7), both the 2,3,7,8-TCDD recovery and its variability are illustrated on Figure 5-20 (cores in lower 14 miles of the LPR only), and the following are observations:

1. There is a clear relationship between net sedimentation rate and the depth of maximum 2,3,7,8-TCDD contamination (see Figure 5-20, Panel c).
2. Cores with higher calculated sedimentation rates tend to have lower surface concentrations (see Panel b) but not lower peak concentrations (see Figure 5-20, Panel a).
3. Widespread burial of the 2,3,7,8-TCDD peaks has occurred such that surface concentrations are often an order of magnitude or more lower than the peak; however, there are also numerous cases where the peak resides at the surface (see Figure 5-20; Panel d), especially in the RM 10.9 mudflat.

The preceding observations do not imply that net sedimentation is the only recovery process affecting 2,3,7,8-TCDD within the LPR; recovery occurs even in the absence of net sedimentation because periodic erosion and deposition are coupled with surface mixing processes (e.g., bioturbation) and the diluting influence of solids originating from the UPR, tributaries, and Newark Bay.

5.4.3 Estimates of Natural Recovery

Rates of natural recovery were estimated by comparing surface sediment concentrations in circa 1995 and circa 2010. The major datasets suitable for this comparison restrict the comparison to the portion of the river between RM 1 and approximately RM 7. The conditions in the two periods were characterized using data collected between 1995 and 1999 (termed "1995") and between 2005 and 2012 (termed "2010").

In examining recovery, bathymetric records were used to partition the channel of the LPR between approximately RM 2.5 and RM 6.8 into three categories: 1) areas that have not accumulated sediments since 1949 (non-depositional regions); 2) areas that accumulated sediments but have been subject to erosion that has returned the surface to elevations within 6 inches of the 1966 surface; and 3) areas of deposition that have not experienced this extent of erosion. Such partitioning makes intuitive sense; non-depositional areas should have low contaminant concentrations, areas that accumulated sediment during the periods of high pollutant loadings in the 1950s and 1960s and now have exposed those sediments because of erosion could have high contaminant concentrations in surface sediments, and areas in which 1960s' sediments remain buried should have intermediate contaminant concentrations reflective of more recent conditions in the river. The channel downstream of RM 2.5 shows concentrations similar to those in the last group mentioned previously. A map of surface sediment contaminant concentrations was developed using Theissen polygon interpolation, with the polygons constrained by the boundaries of the deposition groups (note that the shoals were considered a separate group). Separate maps were developed for sediment data collected from 1995 to 1999, and for data collected from 2005 to 2012.

The concentration maps were examined with the river broken up based on model predicted erosion/deposition[53]. Focusing on 2,3,7,8-TCDD, spatially weighted average concentrations between RM 1 and approximately RM 7 show a logical pattern of recovery, as illustrated on Figure 5-21. Areas predicted to be net erosional show no recovery and an increase in concentration. The predicted mildly depositional areas show essentially no change, whereas

[53] Erosional, mildly depositional and highly depositional regions were defined using the CPG sediment transport model as regions with negative, <1 centimeters per year (cm/yr), and $\geq$1 cm/yr predicted net sedimentation, respectively, over a 15-year calibration period (1995 to 2010).

the highly depositional areas show a decline of roughly 35 percent. Similar analyses for other contaminants are ongoing and will be discussed when those analyses are completed. These inferred trends and their interpretation may be impacted by the assumptions of the contaminant mapping and interpolation methodology, which may be refined in conjunction with RI/FS contaminant fate and transport model development.

It is interesting to note that the recovery in the highly depositional areas is consistent with the trend in fish tissue. A comparison of tissue data collected in 2009 with historical data collected between 1995 and 2005 indicated a decline in TCDD-TEQ (toxic equivalents quotient) tissue concentration for several species of fish and for blue crab (see Figure 5-22). Tissue concentrations declined between 32 and 64 percent. This correspondence is not surprising because the surface sediment contaminant concentrations in the highly depositional areas reflect the concentrations on water column and recently deposited particulate matter, which are the food sources at the base of the food web.

5.4.4 Ongoing/Future Natural Recovery

Sediments with high surface concentrations can inhibit natural recovery by behaving as an internal contaminant source—they can actively flux high concentrations to the water column and thus impact other regions. In the absence of these internal sources (i.e., through remediation), faster natural recovery would be expected.

Recovery is likely affected by the following other factors:

- Concentrations approaching regional background: The rate of natural recovery is dependent on the difference between concentrations on depositing particles and the local concentration in the bed. This can be readily demonstrated mathematically[54] for the simple conceptual model above. For a number of contaminants, the concentrations on particles entering from the watershed and

[54] More specifically, it can be shown that the decline due to burial is not expected to be a first-order process due to the regional background concentration on depositing particles. Over time, this would cause half-lives to increase as background is approached.

Newark Bay are similar to the concentrations in the LPR sediments, thus limiting the potential for further recovery.

- The decline in regional background (i.e., external sources) is likely slowing: As a contaminant approaches background, any further decline depends on the rate of decline in the regional background. The decline of regional background is expected to slow over time as the impact of previously implemented source control measures becomes less on an incremental basis, such that the decline in regional background is progressively driven more and more by natural recovery processes. This effect is contaminant specific.
- LPR burial rates are likely declining: The rate of recovery is influenced by the net deposition rate, which is slowing from historical levels as the system approaches dynamic equilibrium, as previously discussed. However, burial should continue as the river maintains pace with sea level rise; 29 to 53 cm of sea level rise is predicted by 2080 (Gornitz 2007). The burial rate effect is location specific but not contaminant specific.

6 SUMMARY

6.1.1 Major Conceptual Site Model Components

The LPR has been an effective trap of both sediments and contaminants for the past 60 years. As with most urban systems, it has been subjected to a broad range of contaminant loadings from multiple sources (e.g., untreated industrial and municipal wastewater, CSOs/SWOs, direct runoff, atmospheric deposition). These sources discharged directly or indirectly to the LPR or entered via its upstream/downstream boundaries and tributaries from across the NY/NJ metropolitan area. 2,3,7,8-TCDD that originated from the Lister Avenue Site in Newark, NJ, resides in the river sediments at levels atypical of other urban sites. 2,3,7,8-TCDD levels in surficial sediments are the major human health risk driver for the LPRSA and also result in potential risks to some ecological receptors. Peak loading for 2,3,7,8-TCDD and most of the other major contaminants appears to have occurred in the early 1960s or earlier, based on core profiles, and declined following the 1972 Federal Water Pollution Control Act amendments. Urbanization and industrial development have also severely degraded the habitat quality along the river, resulting in the loss of wetlands and habitat, and a general lack of shoreline vegetation.

The system has been recovering since the 1970s with infilling of the LPR. Contaminated sediments have been buried under cleaner, less contaminated sediments and are continually diluted as cleaner sediments deposit and are down-mixed. Burial has slowed as the river has become shallower and the navigation channel has not been maintained; Cs-137 levels suggest that burial slowed in some locations starting in the 1960s, leaving elevated contaminant concentrations at or near the sediment surface. Limited areas have been identified where historically buried contaminated sediments are experiencing periodic erosion and slowing continued recovery. Targeted remediation in slowly recovering areas, including mudflats where high contaminant concentrations are detected in the surface sediments, will help enhance recovery and more rapidly reduce risk relative to what can be achieved naturally.

The contaminant patterns in LPR sediments reflect physical transport processes and past and present contaminant loadings. Contaminants tend to be associated with finer sediments, with the bulk of the chemical inventory residing in the thick sediment bed of the lower

8 miles and in depositional pockets further upstream. The longitudinal distributions of contaminants suggest the following:

- Surface sediment 2,3,7,8-TCDD concentration trends are consistent with a Lister Avenue Site source and upstream transport to approximately RM 14.
- The concentrations of all contaminants except 2,3,7,8-TCDD are similar to watershed (upstream or tributary) and/or downstream sources (from Newark Bay and beyond).
- Concentration gradients tend to be muted over the lower 12 miles, presumably due to tidal mixing and sediment redistribution processes.
- Concentrations of contaminants dominated by sources in the lower 12 miles of the LPR or Newark Bay decrease upstream of RM 12 due to the declining influence of tidally induced upstream sediment movement.
- Concentrations of contaminants dominated by sources upstream of Newark Bay decrease into Newark Bay due to dilution with water and solids in the bay.

A central component of the CSM is the interpretation of contaminant distributions in the context of ongoing external sources. External sources can limit the achievable benefit of active remediation due to the potential for recontamination and will dictate future recovery of the system in the absence of remediation. The data suggest the following:

- Upstream loading at Dundee Dam and downstream loading at Newark Bay likely have the most influence on surface sediment concentrations, with tributaries and CSOs/SWOs expected to play a more localized role.
- All contaminants except 2,3,7,8-TCDD have concentrations similar to upstream and downstream sources. This may limit the extent to which significant long-term concentration reductions may be achieved by active remediation of the LPR in the absence of region-wide source control.
- Ongoing sources may also interfere with the achievable risk reduction by contributing non-chemical stressors, such as nutrients and pathogens.

The LPR sediment deposits are largely stable, as suggested by comparisons of bathymetric surveys, sediment core contaminant concentration profiles and radionuclide concentrations, and calculations of scour during high flow events using model and data-based approaches. Bathymetric datasets indicate a net depositional environment with evidence of moderate erosion during high flow events, forming pockets of deeper scour in localized areas often associated with geometric features in the river (e.g., outer bends, obstructions, and channel irregularities).

Natural recovery of surface sediment contaminant concentrations has been ongoing on average but with spatial variability (e.g., not in areas with historical deposition that have experienced net erosion since the 1990s). Natural recovery may slow in the future for the following reasons: 1) concentrations are approaching regional background for many contaminants; 2) the rate of decline in the contaminant-specific regional background is likely decreasing; 3) LPR burial rates are likely declining; and 4) the importance of the LPR internal contaminant source may be increasing as areas not recovering begin to control concentrations on particles depositing in the recovering depositional areas.

Non-chemical stressors, such as the extensive hardened shoreline, nutrients and pathogens, and invasive species, also limit the continued improvement of the LPR. Non-chemical stressors and sources such as storm water runoff will need to be addressed to achieve a sustainable remedy for the LPRSA.

6.1.2 Implications for Remedial Design

The CSM supports a remedial alternative that targets areas with high 2,3,7,8-TCDD surficial concentrations, which are likely inhibiting the recovery of other areas of the river. A remediation strategy targeting these areas will achieve significant near-term risk reduction by quickly removing sediments with higher concentrations and longer term ongoing risk reduction by accelerating recovery in areas not subject to active remediation. This will also reduce contaminant concentrations on depositing particles, resulting in a continued decline in surficial contaminant concentrations. For some contaminants (specifically, 2,3,7,8-TCDD), potential ongoing external sources will not contribute to significant recontamination, and recovery can be greatly enhanced. For others (e.g., PCBs and PAHs), the extent of recovery is limited by the recontamination that will occur following remediation.

Although a final remedial design would need to consider risk across all contaminants, the well-correlated surface sediment contaminant concentrations suggest that targeting high concentration areas based on the major risk driver (2,3,7,8-TCDD) would also approximately target the contributions of other contaminants to ecological and human health risk, within the lower 12 to 14 miles where the highest 2,3,7,8-TCDD concentrations are observed. This approach also makes sense given that 2,3,7,8-TCDD is the only contaminant for which recontamination potential is not a major concern; when coupled with the risk weighting, remediation of 2,3,7,8-TCDD stands out as having by far the largest potential for long-term remedial benefit.

Remedial designs involving watershed source control should consider the relative influence of external sources on each of the contaminants while selecting control measures. For example, data indicate that such measures would be important to reduce risks associated with contaminants other than 2,3,7,8-TCDD and non-chemical stressors such as pathogens.

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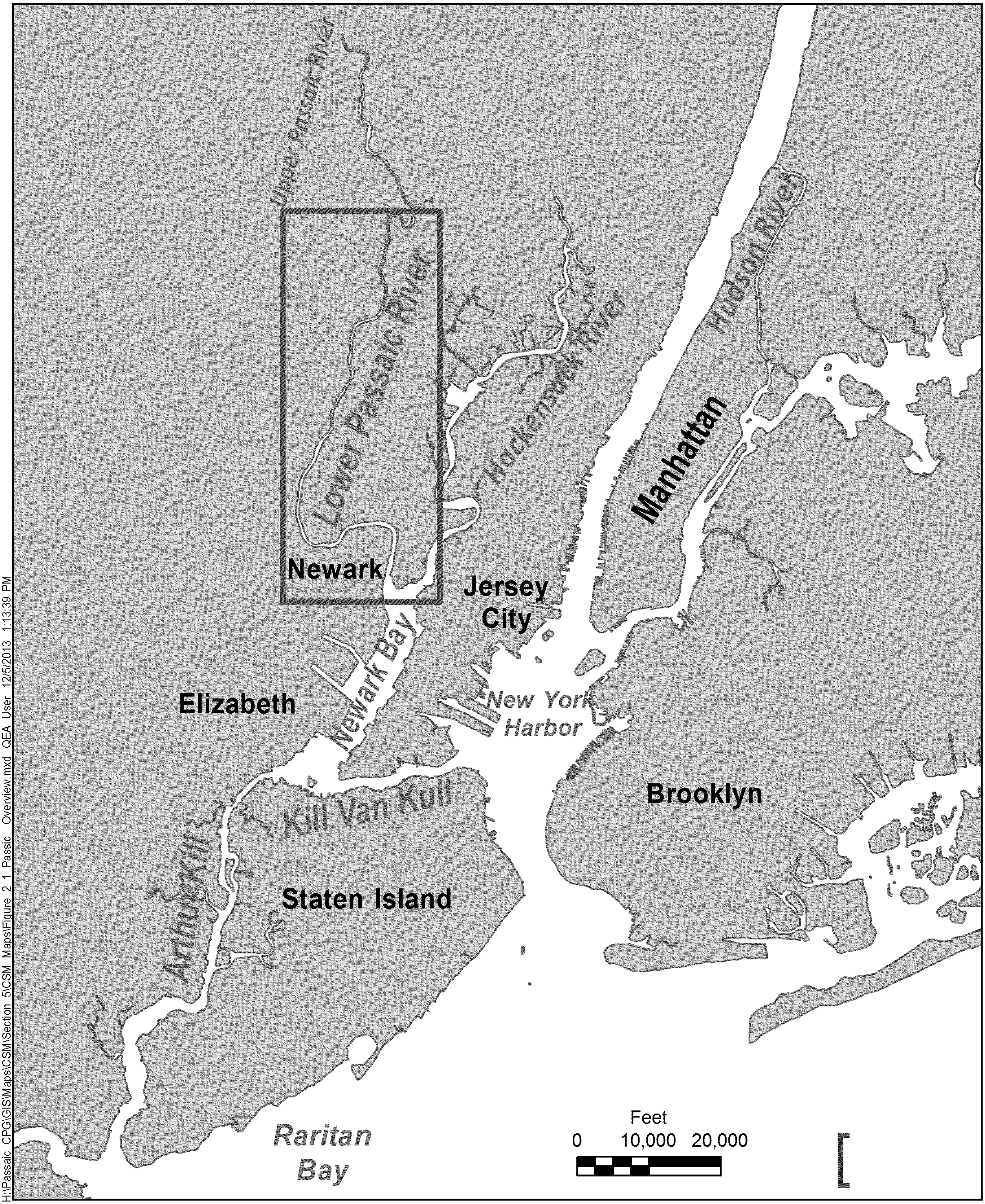
FIGURES



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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 2-1
Map of the Lower Passaic River and Surrounding Regions
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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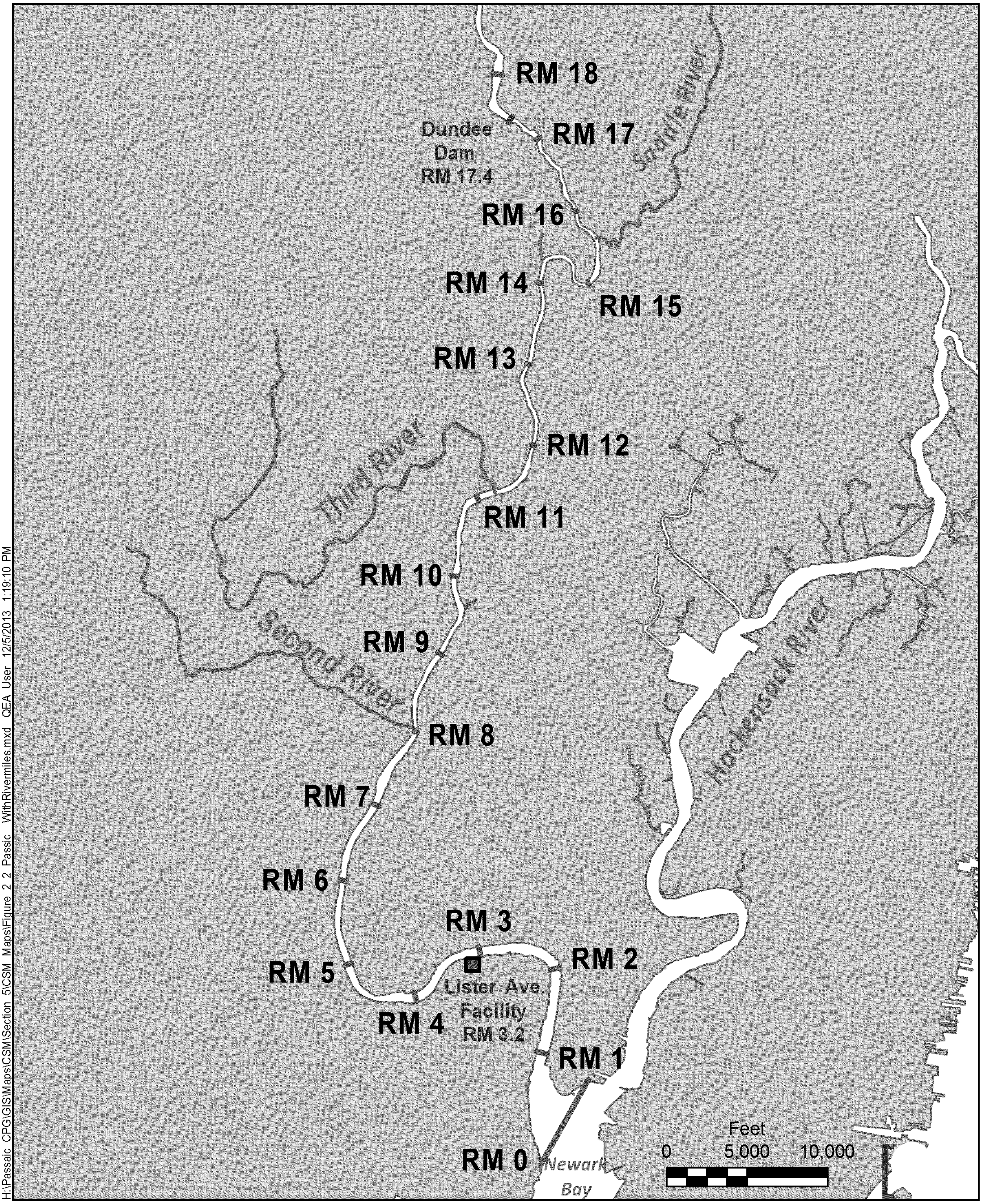

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Figure 2-2
Map of the Lower Passaic River
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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Figure 2-4

Footprint of Phase 1 and Phase 2 Removal Actions by Lister Avenue Facility
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

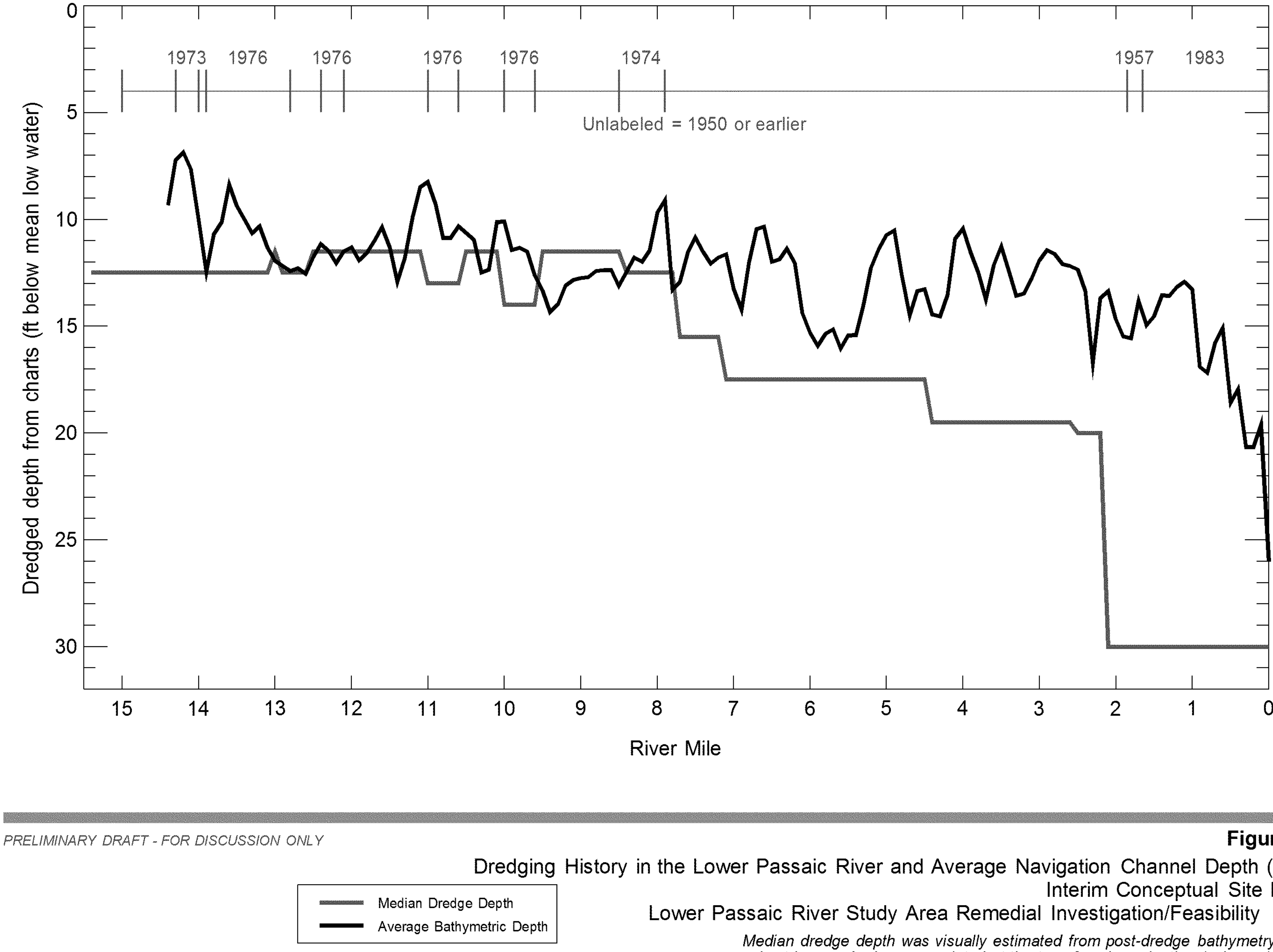

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Figure 2-5

Dredging History in the Lower Passaic River and Average Navigation Channel Depth (2007)

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Median dredge depth was visually estimated from post-dredge bathymetry charts

Last known dredge year printed at the top of each navigational channel section

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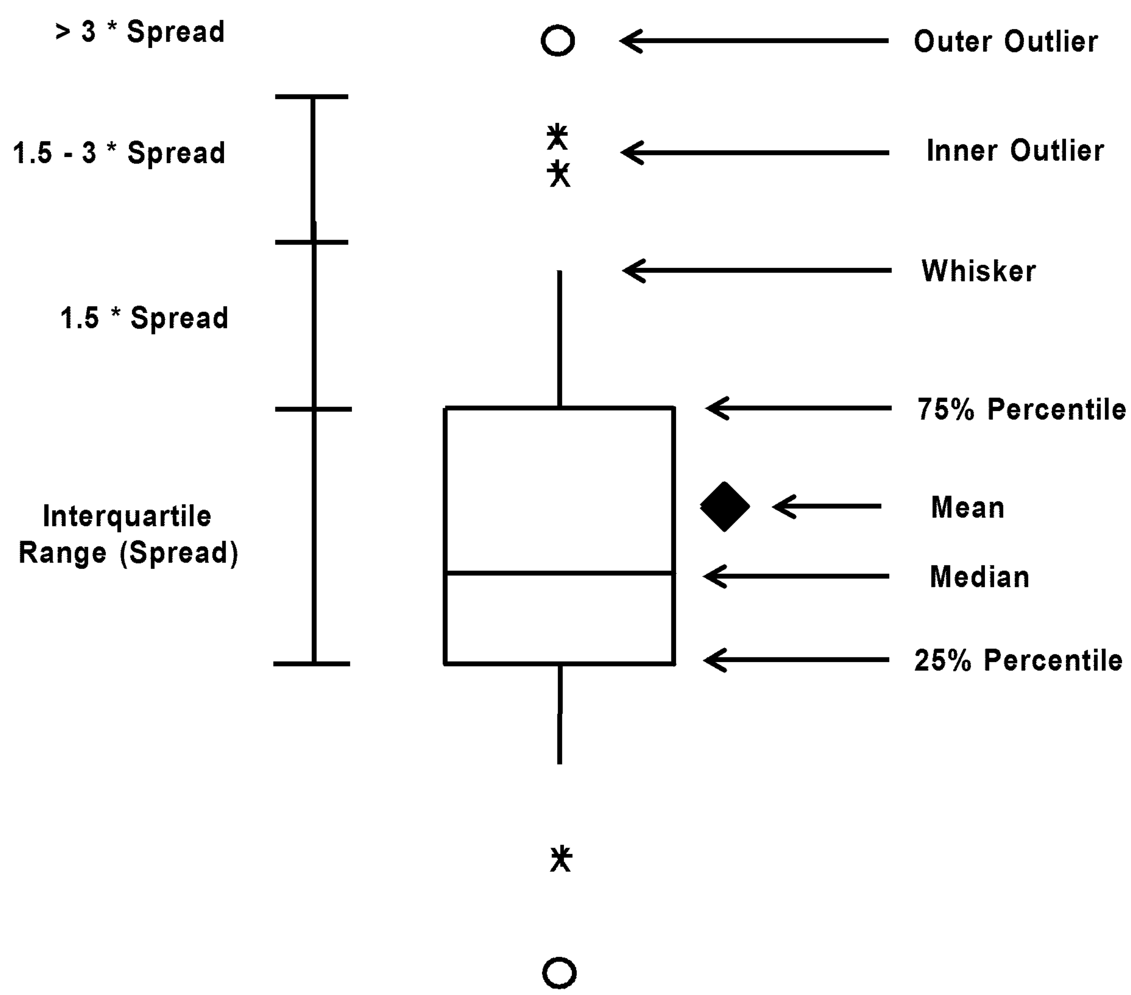
Figure 2-6
Shoreline Type
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



Note: Whiskers extend to the largest (and smallest) observation within the range of 1.5 * Spread.

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Figure 3-1
Schematics of a Box and Whisker Plot
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

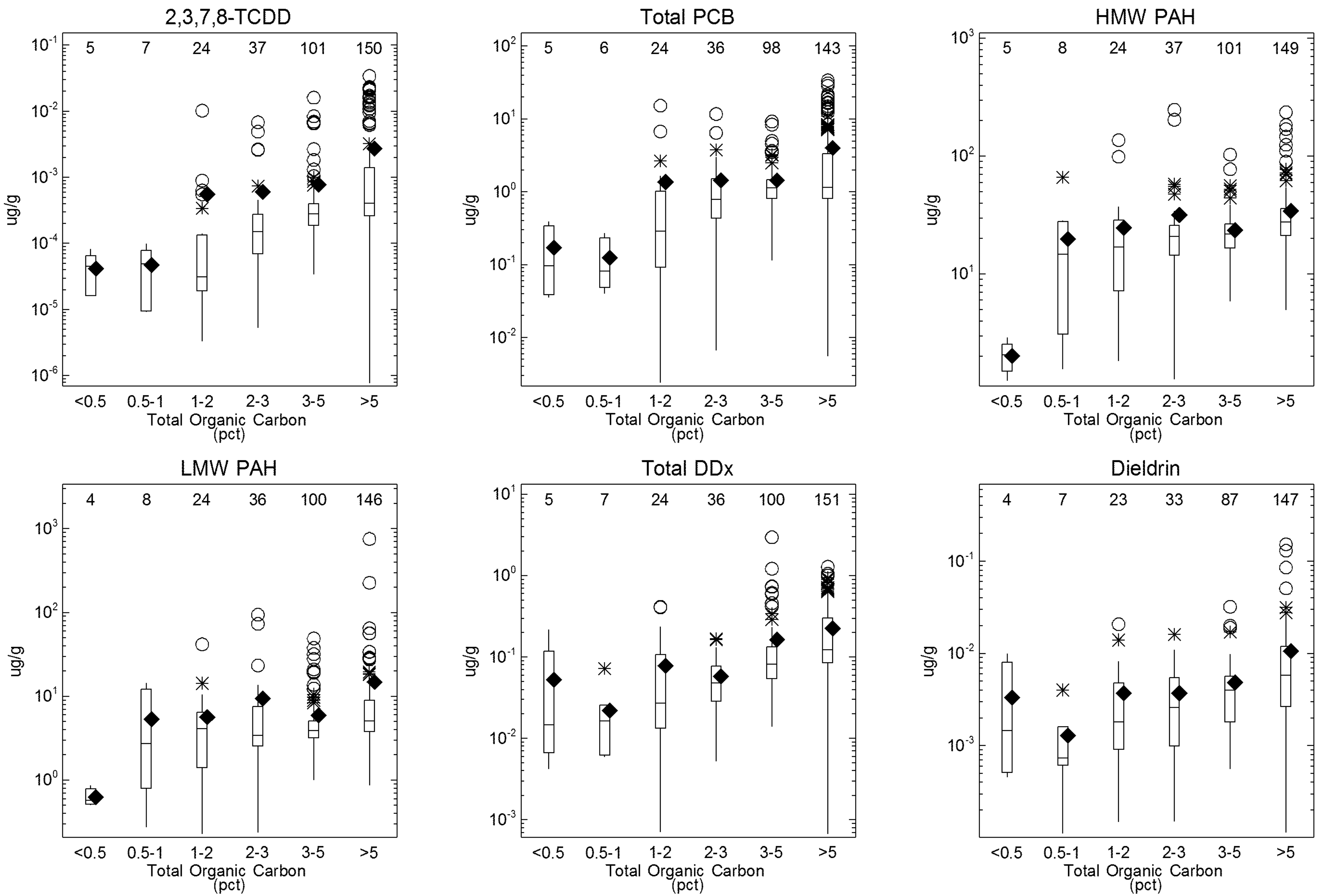

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Figure 3-2a

Contaminant vs. OC Cross Plots
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Only surface samples are shown
Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded
Tributary data excluded. Only samples collected in the lower 12 miles of the LPR used
Numbers indicate sample counts in corresponding bin

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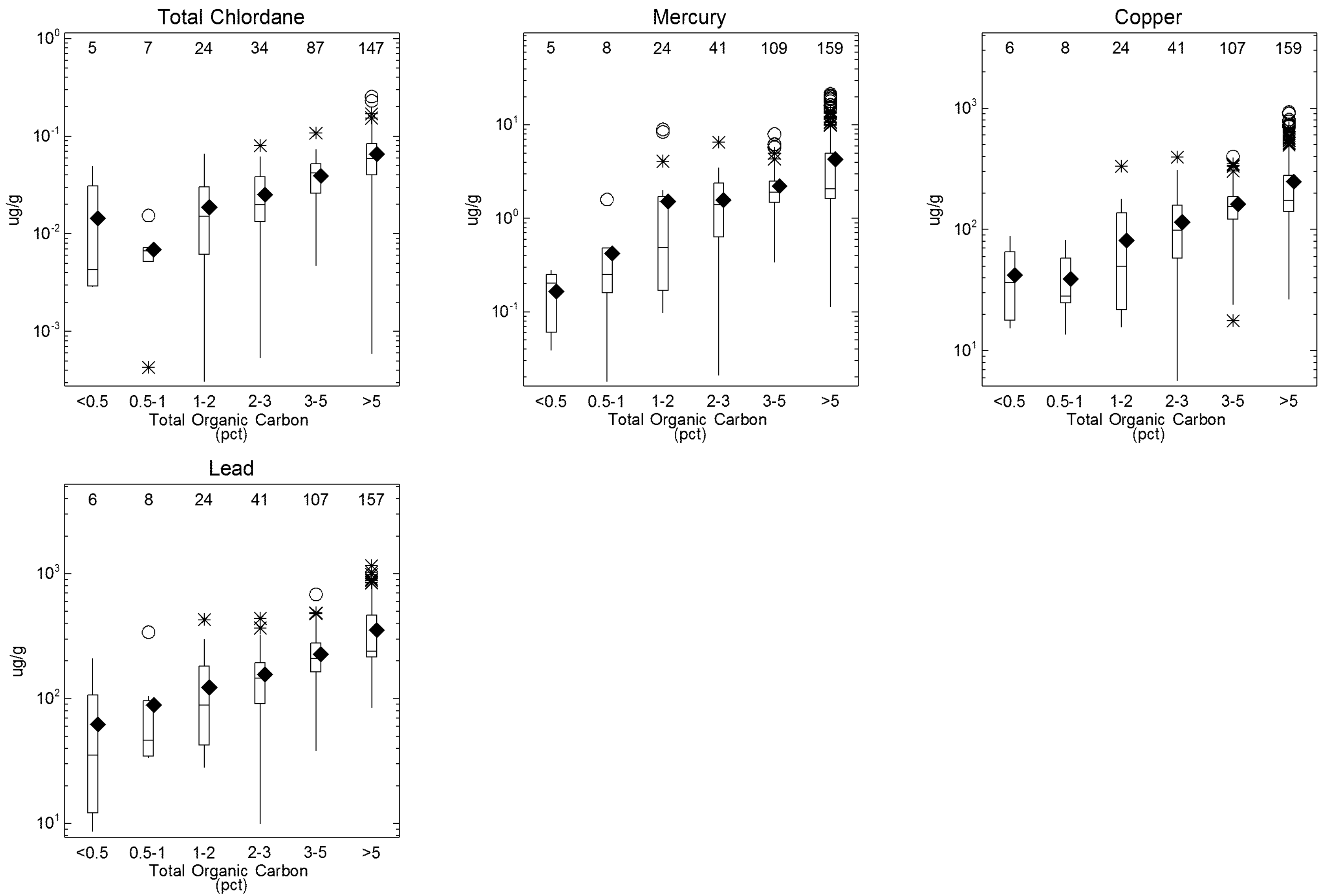

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-2b

Contaminant vs. OC Cross Plots
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Only surface samples are shown
Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded
Tributary data excluded. Only samples collected in the lower 12 miles of the LPR used
Numbers indicate sample counts in corresponding bin

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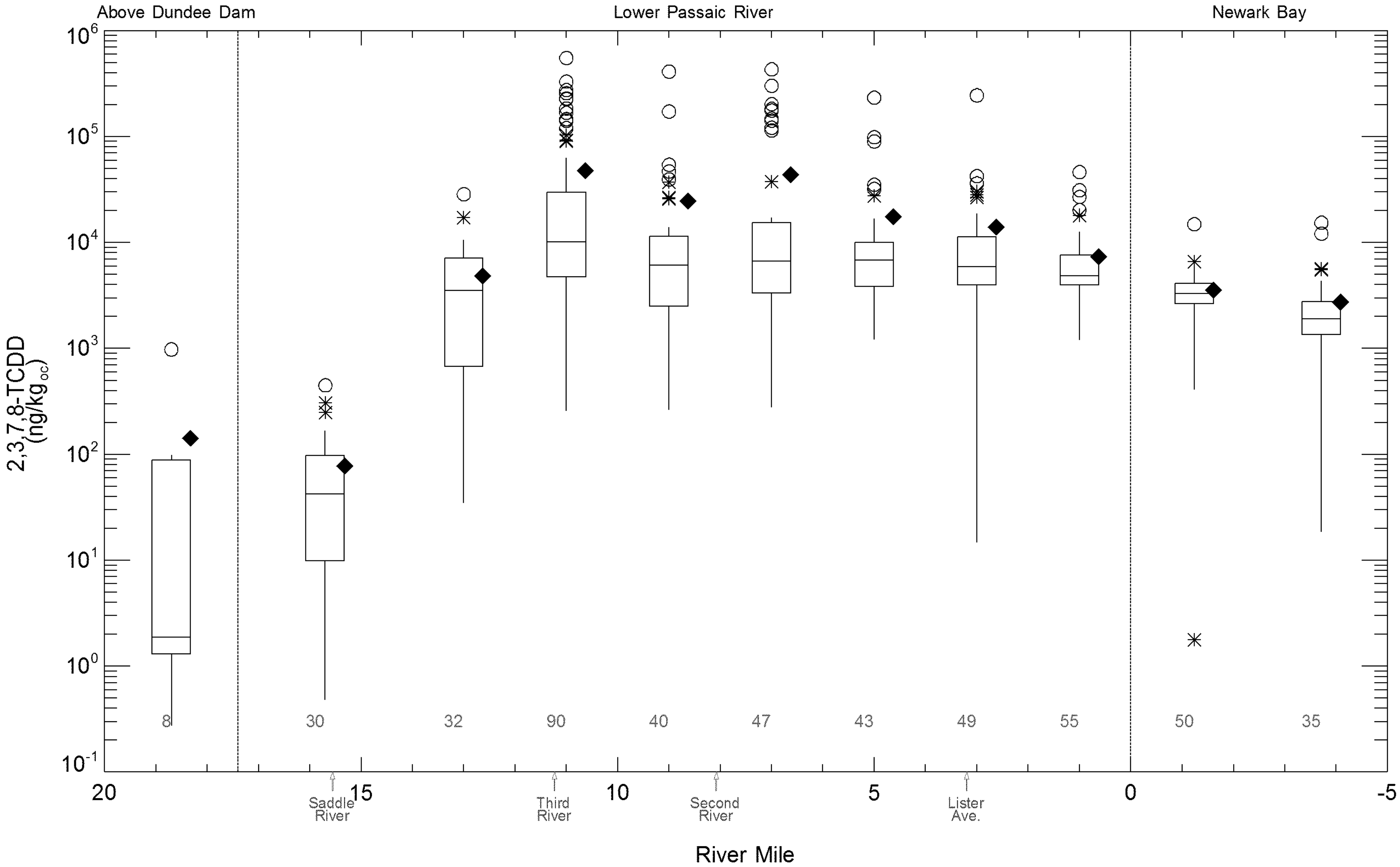

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3a

2,3,7,8-TCDD Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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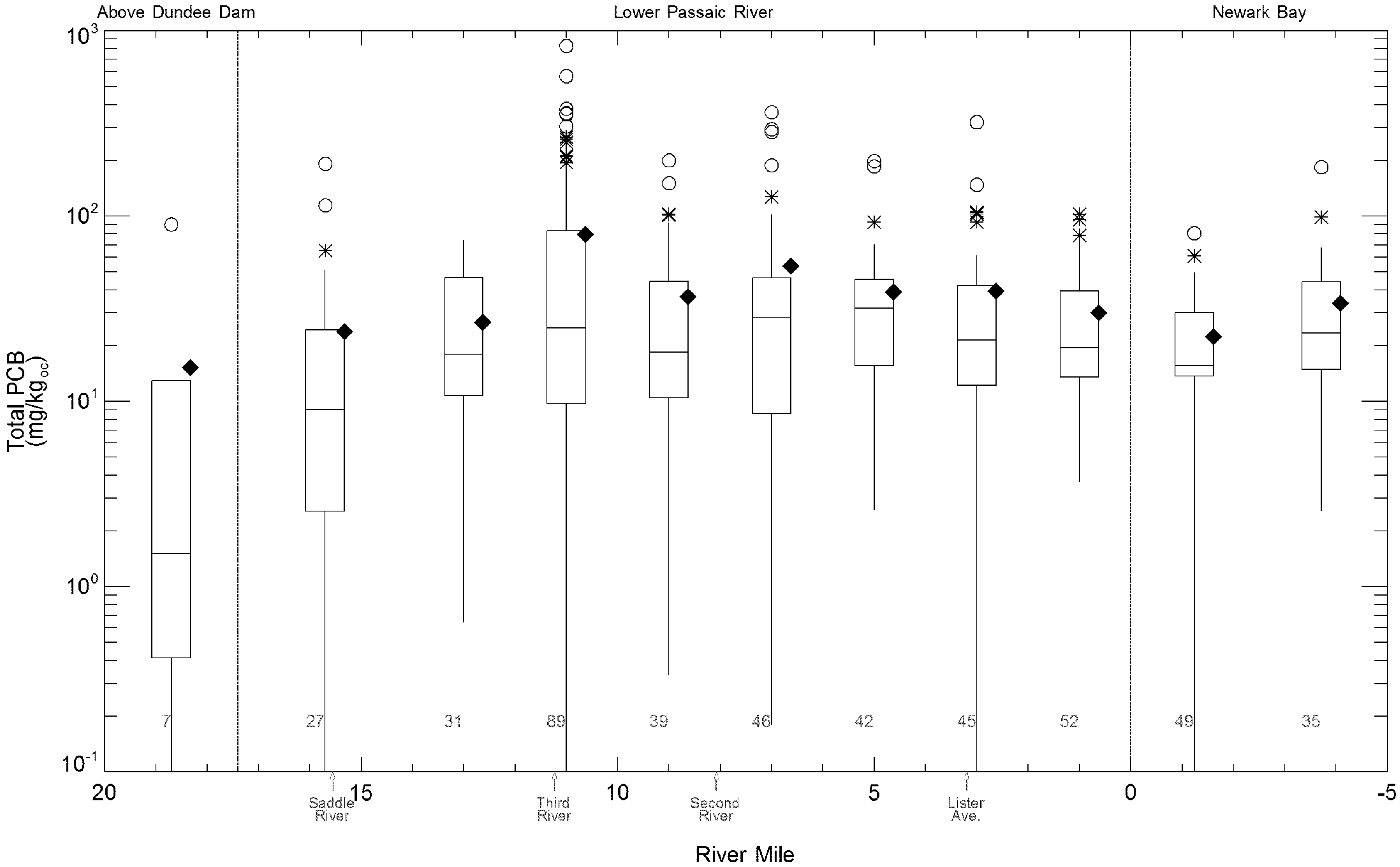
Mon Dec 16 11:36:52 2013



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3b

Total PCB Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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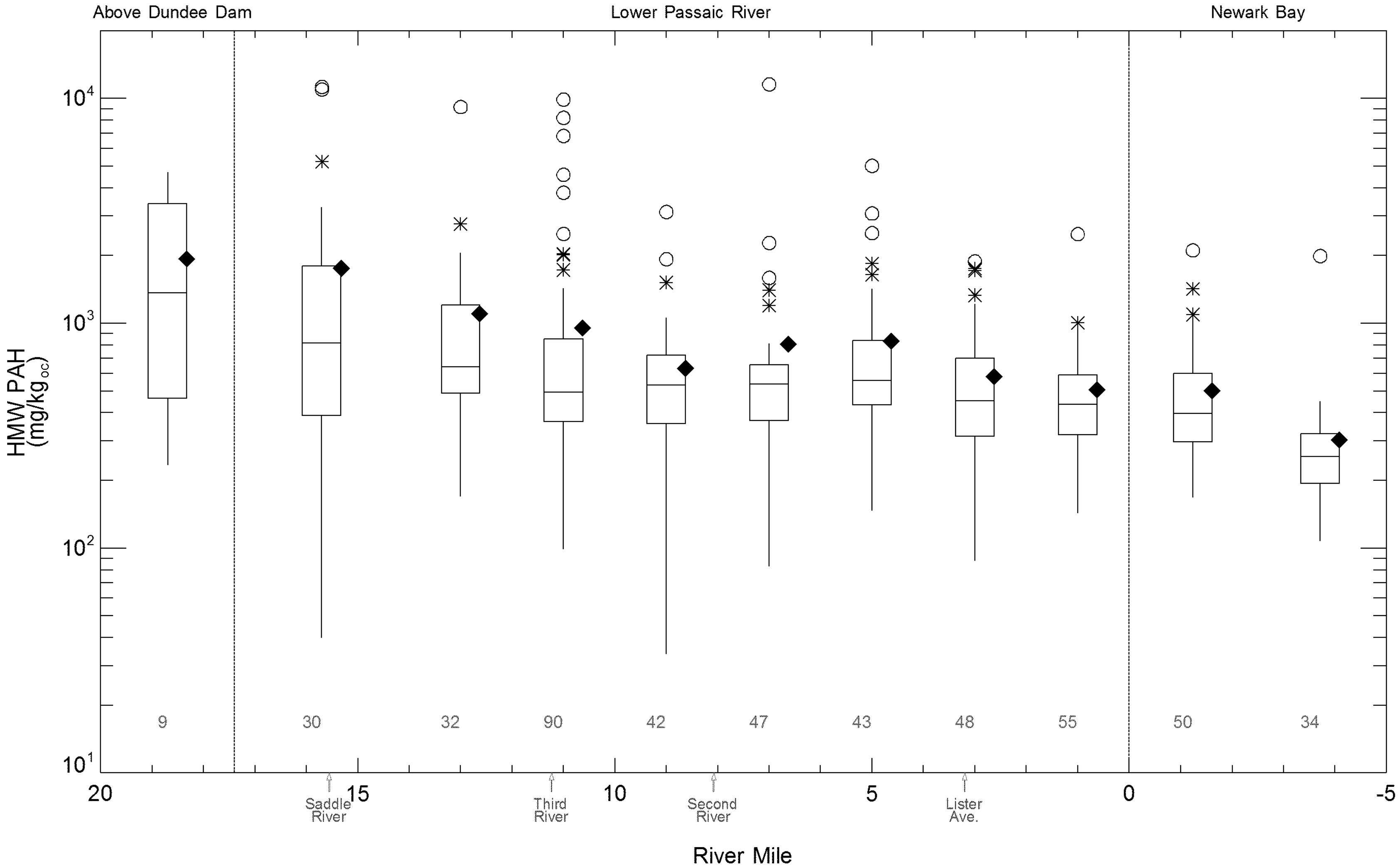

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3c

HMW PAH Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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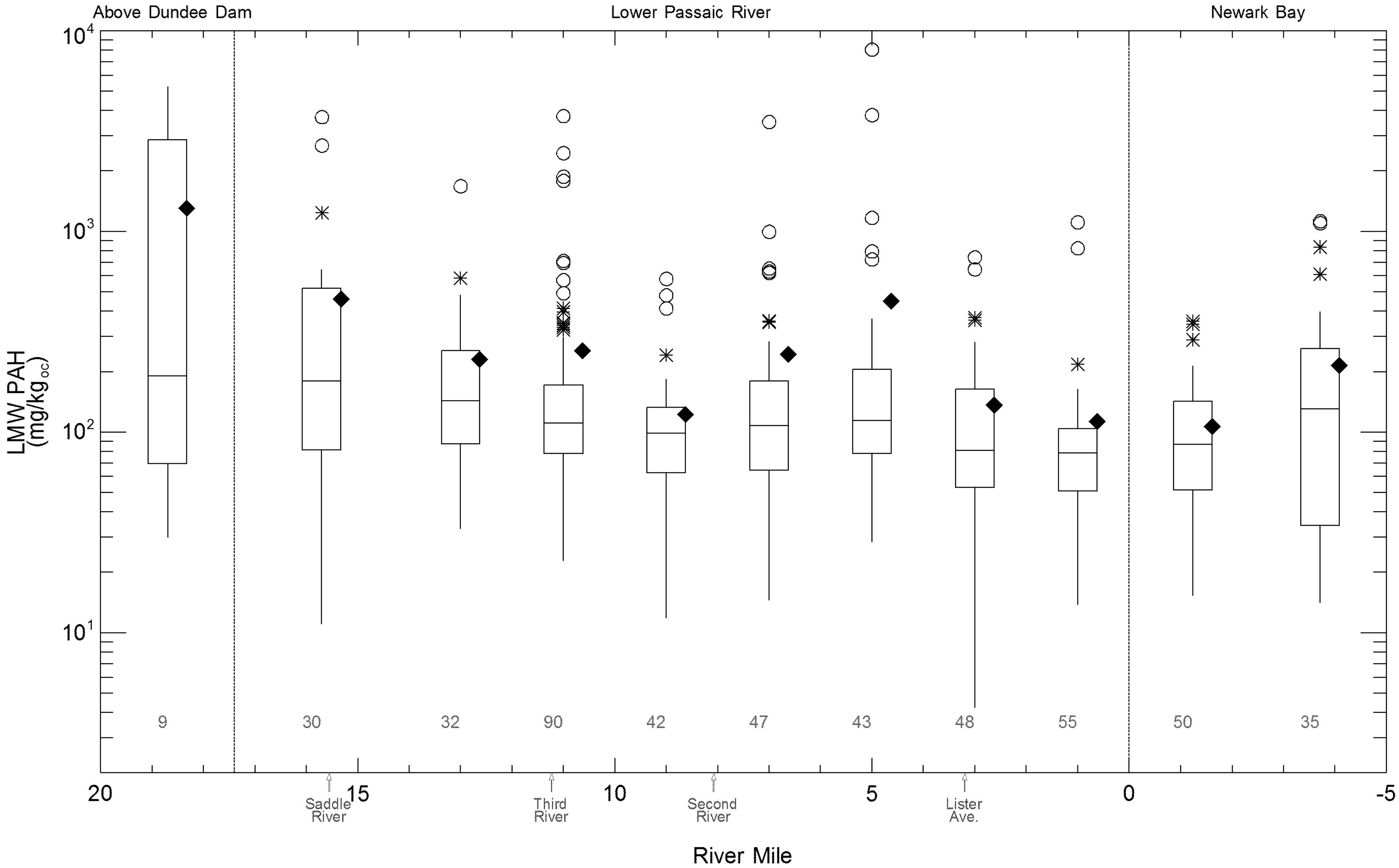

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3d

LMW PAH Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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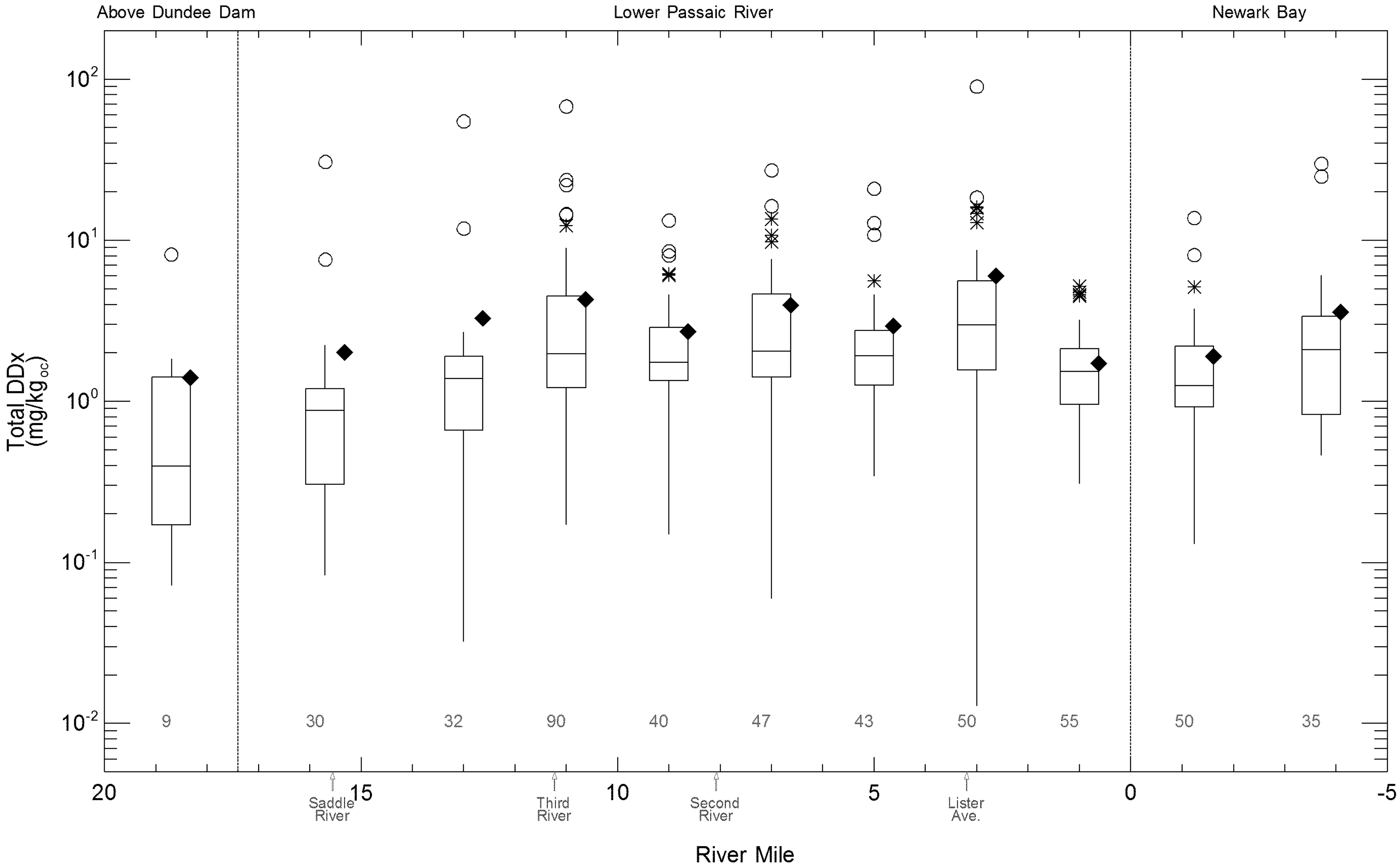

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3e

Total DDx Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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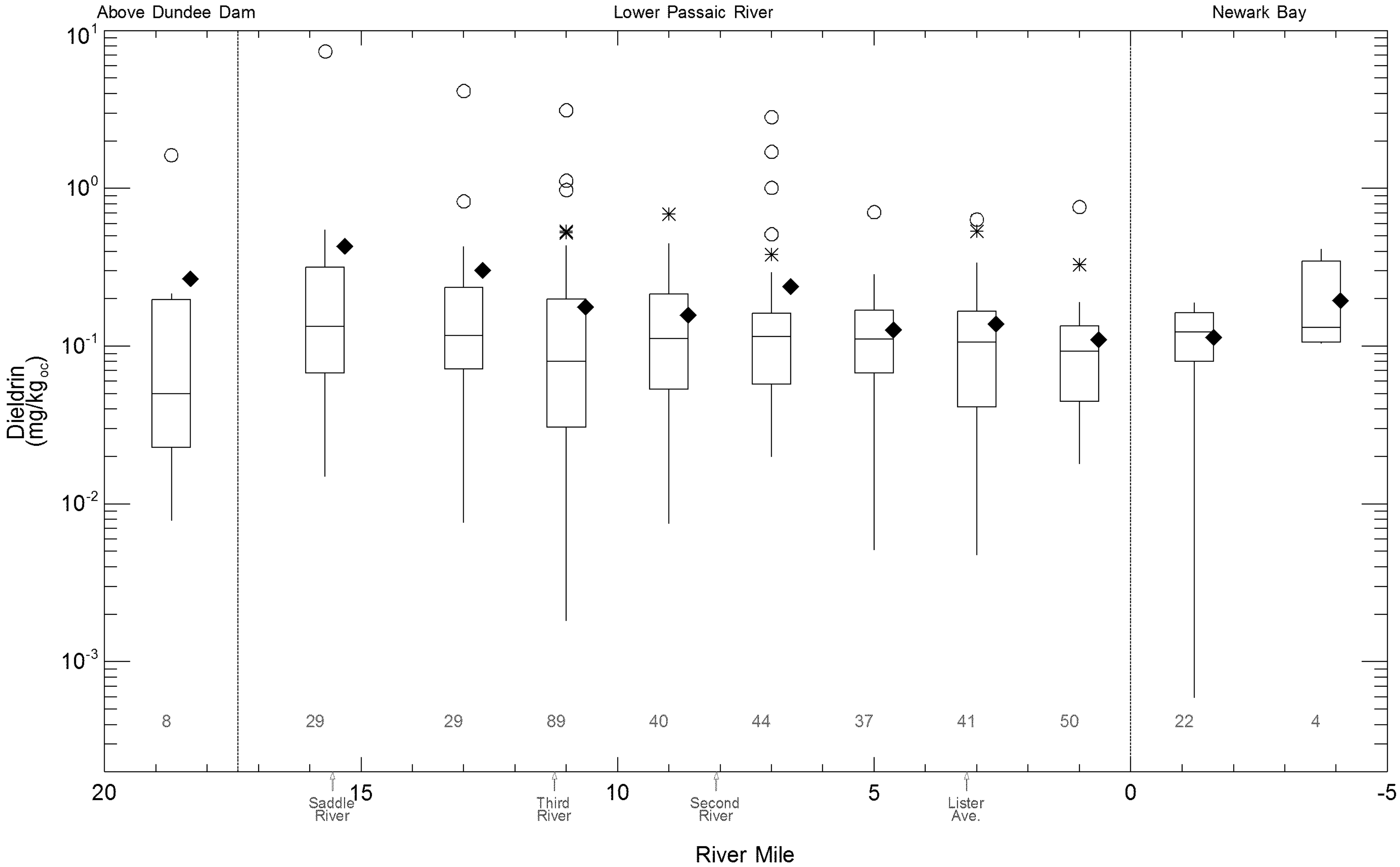

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3f

Dieldrin Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin
Dieldrin ND samples have been excluded due to high reporting detection limit

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\pascpg_copc_2milebinspa tial_boxplotter.pro
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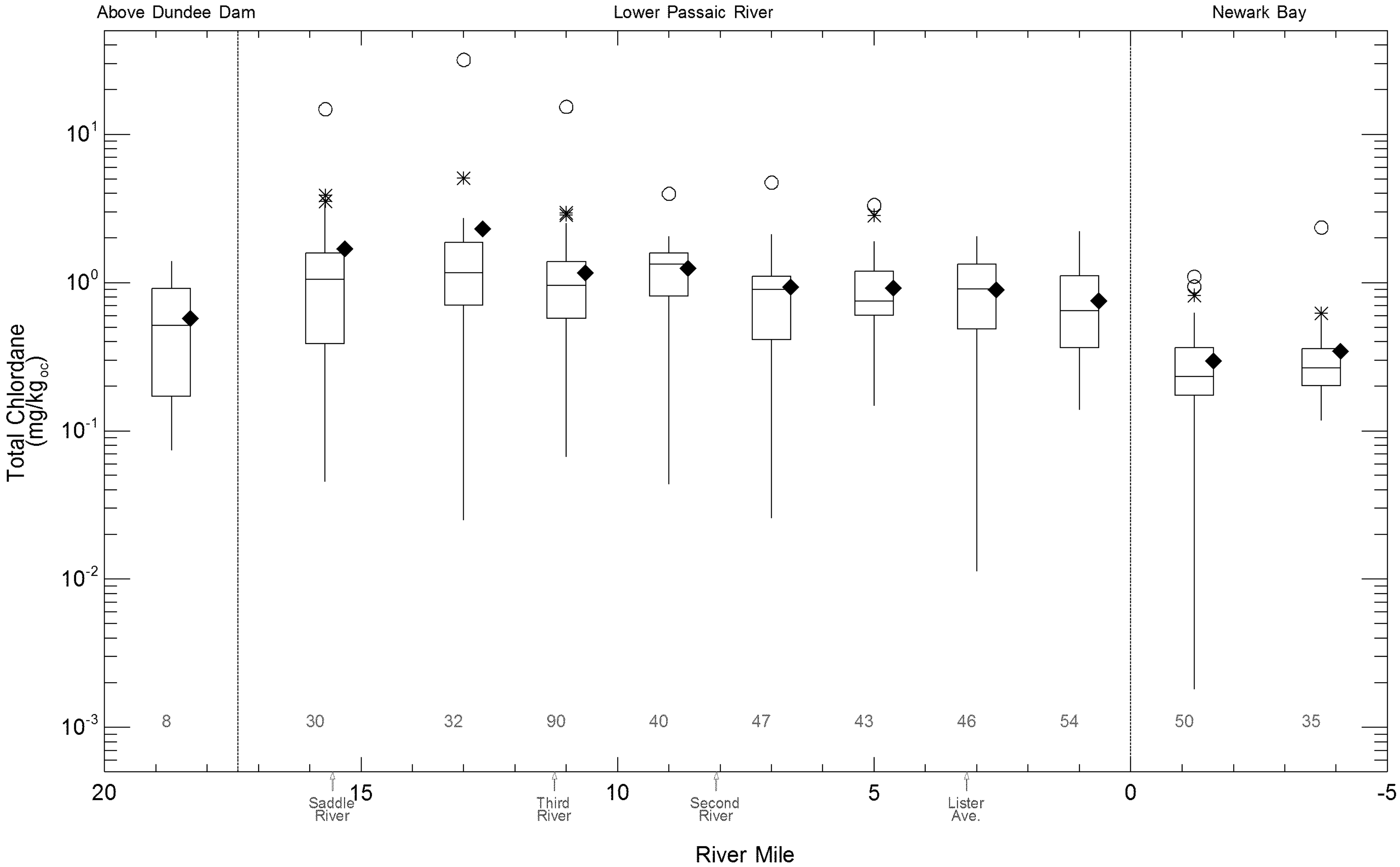


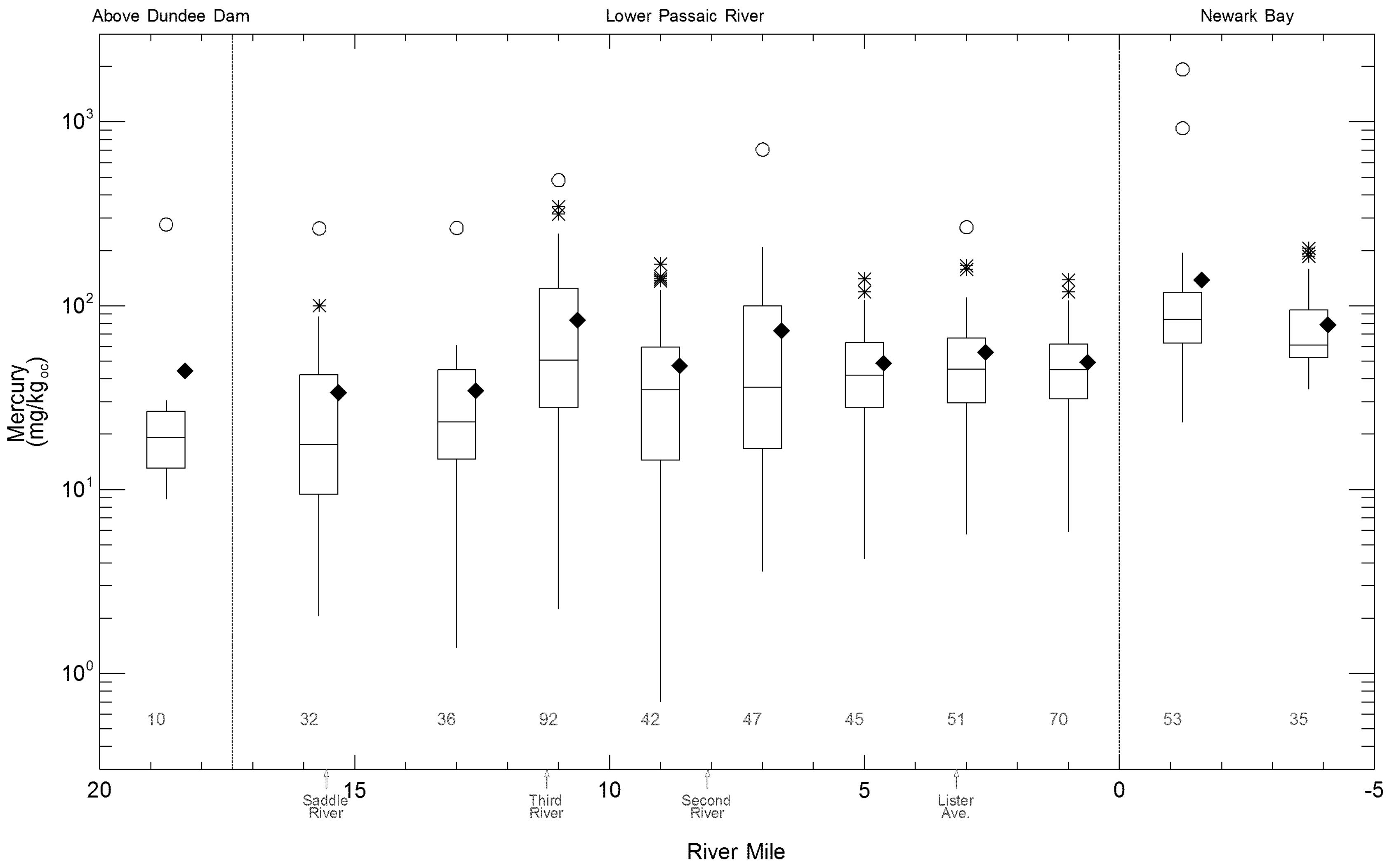
PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3g

Total Chlordane Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\pascpg_copc_2milebinspa tial_boxplotter.pro
Mon Dec 16 11:36:52 2013



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3h

Mercury Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\pascpg_copc_2milebinspa tial_boxplotter.pro
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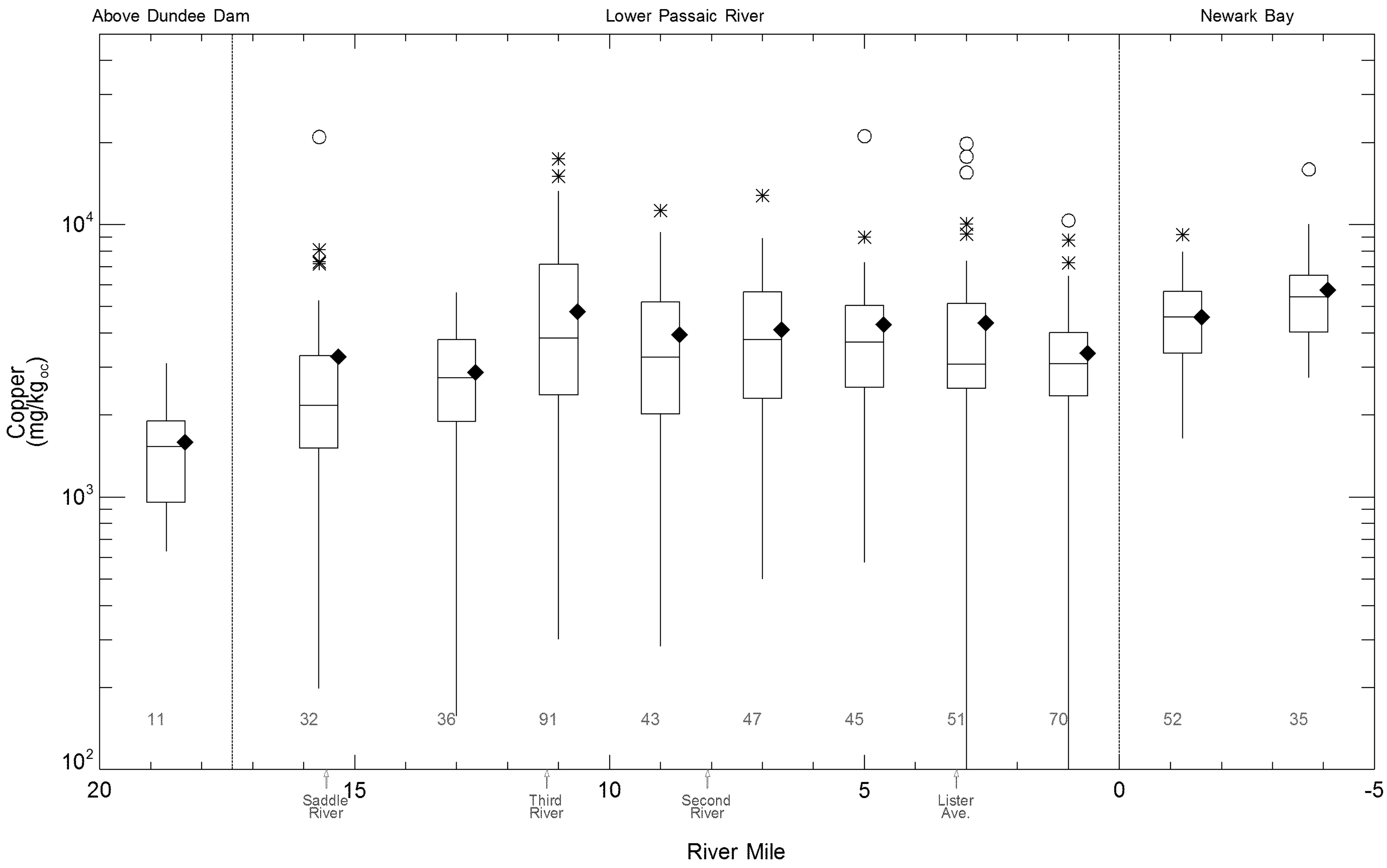

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3i

Copper Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\pascpg_copc_2milebinspa tial_boxplotter.pro
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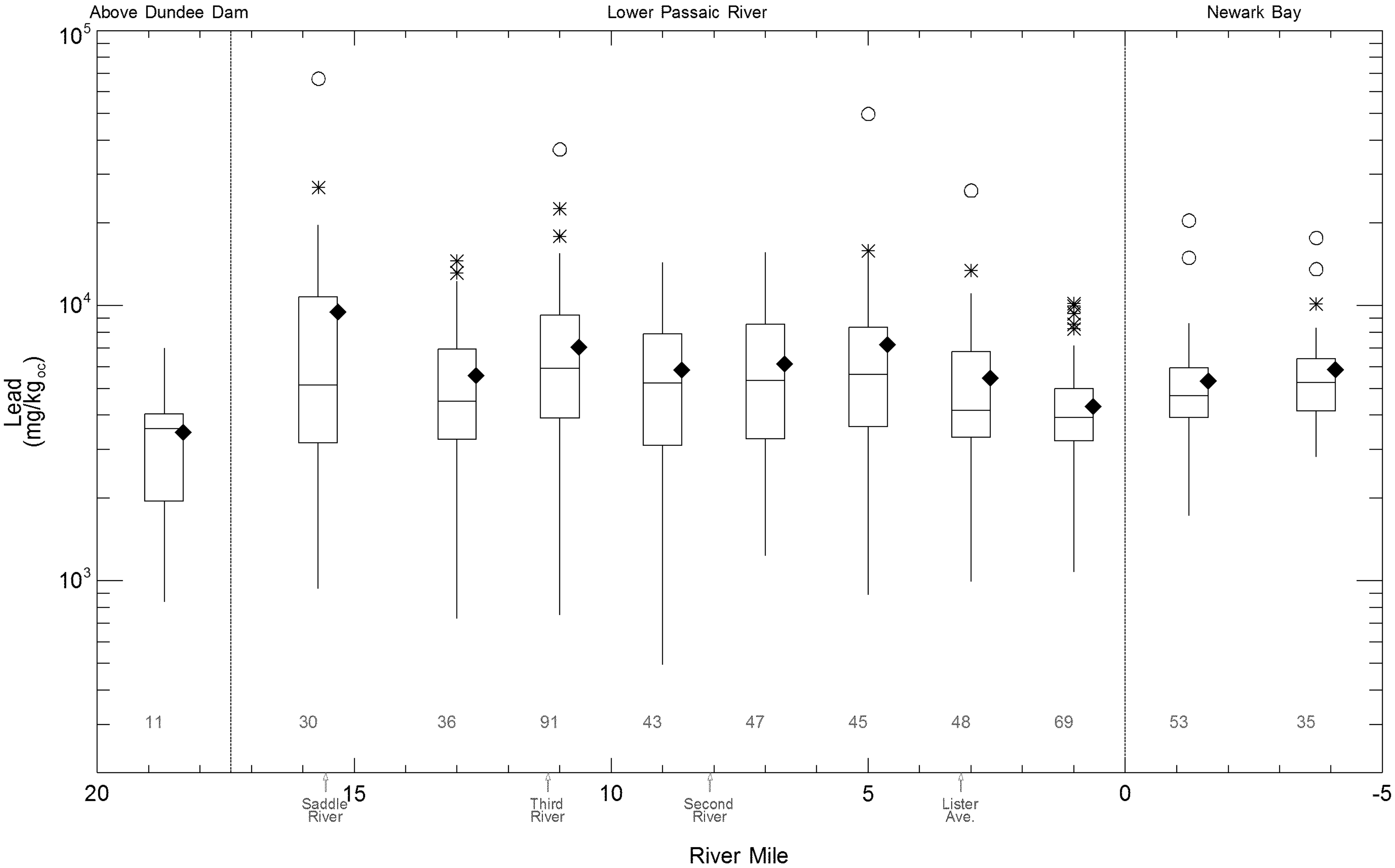

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-3j

Lead Concentrations in Surface Sediments of LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded. Plot includes all samples with a bottom slice depth of 6 inches or less
Blue numbers indicate sample counts in corresponding bin

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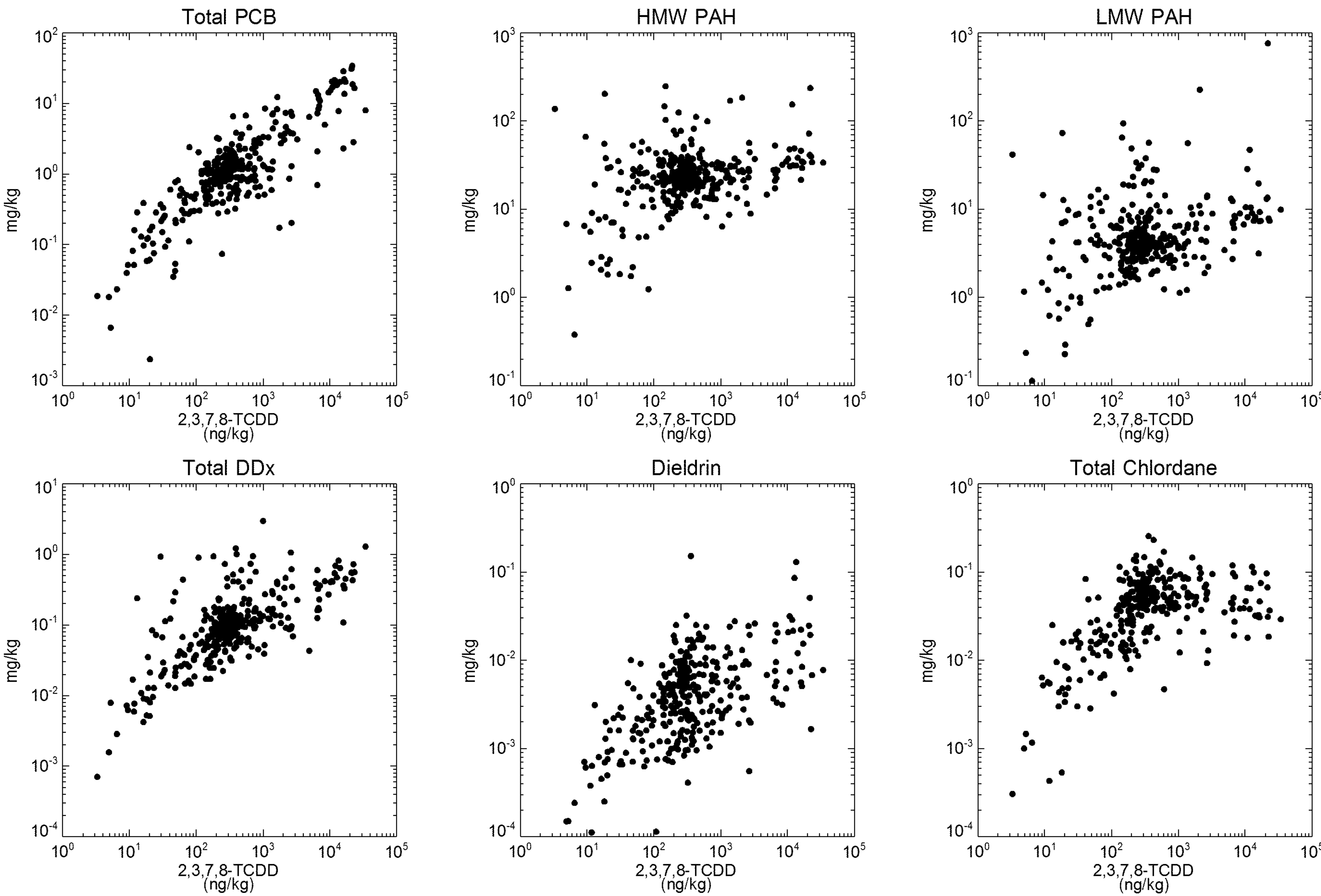

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-4a

Contaminant vs 2,3,7,8-TCDD Cross Plot

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Only surface samples are shown
Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded
Tributary data excluded. Only samples collected in the lower 12 miles of the LPR used

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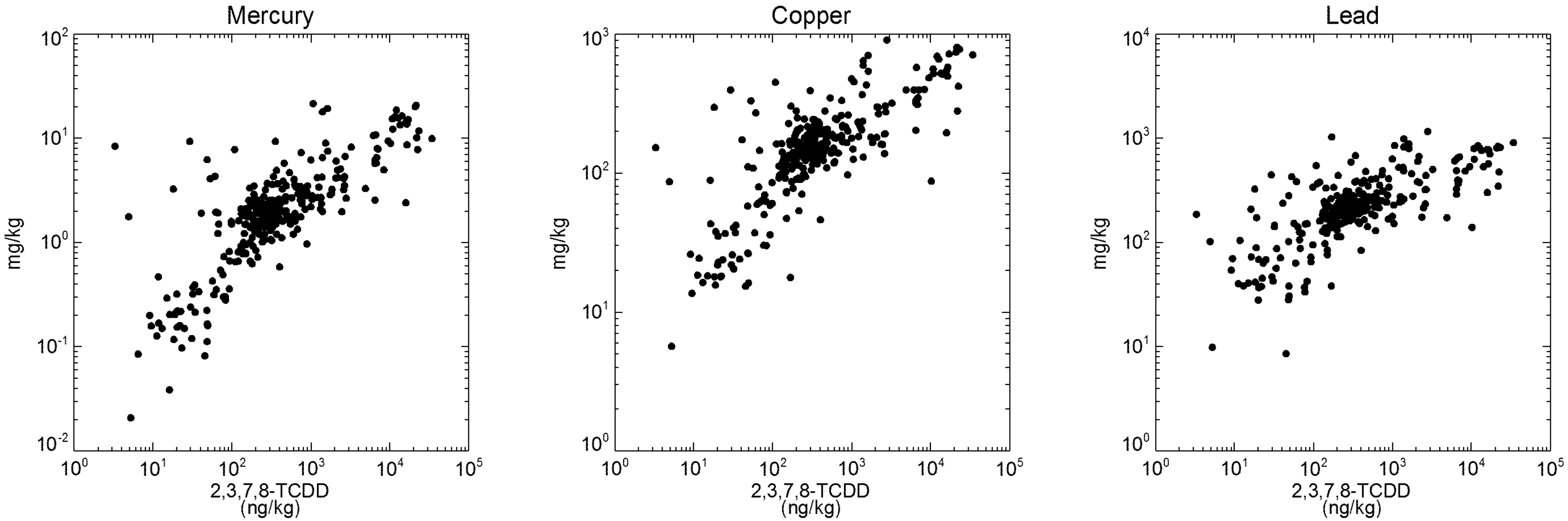


PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-4b

Contaminant vs 2,3,7,8-TCDD Cross Plot
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Only surface samples are shown
Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded
Tributary data excluded. Only samples collected in the lower 12 miles of the LPR used

sm - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\copc_vs_tcdd_crossplots .pro
Tue Dec 17 15:13:06 2013

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

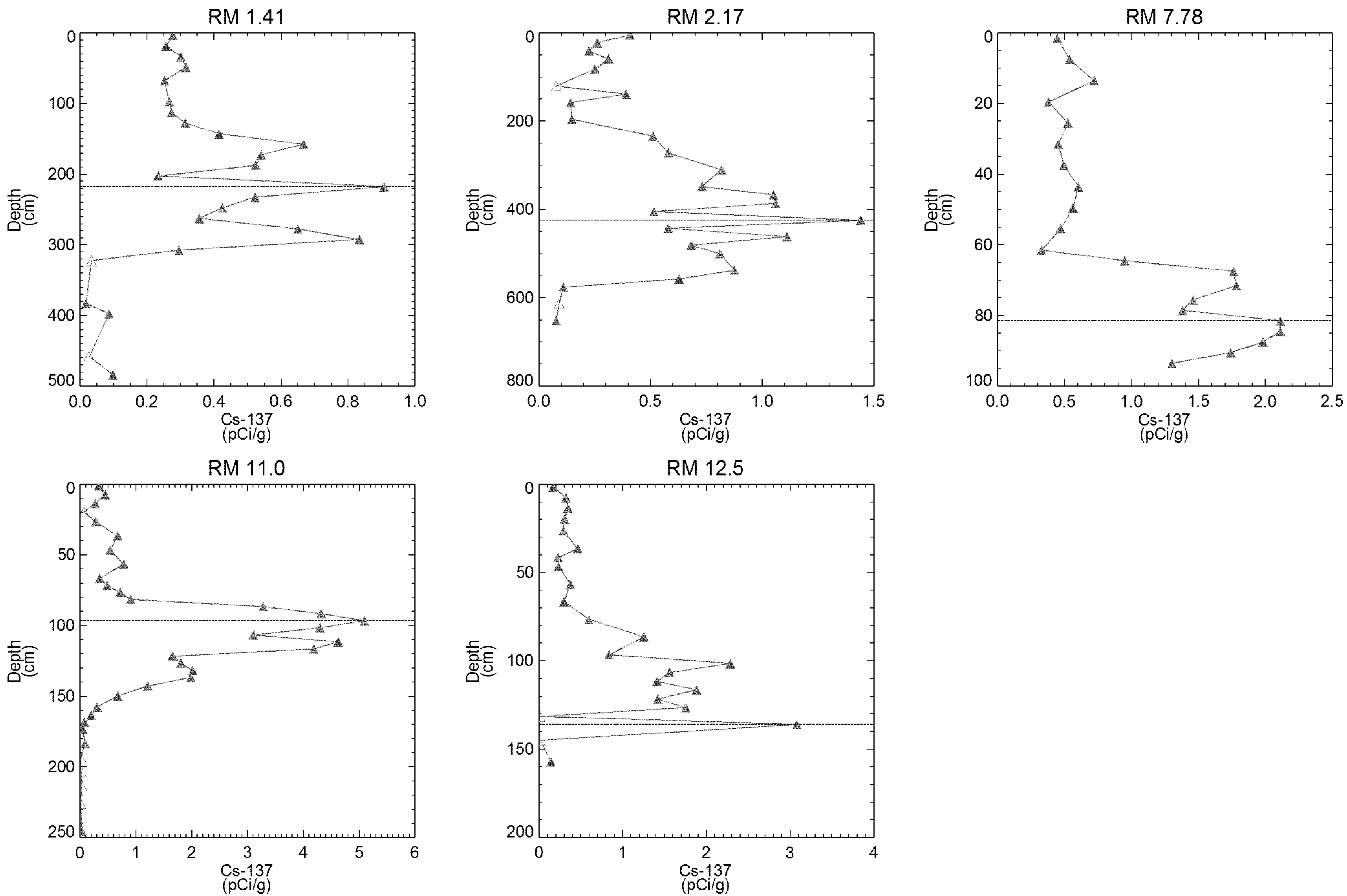
Figure 3-5

Concentration Profile of 2,3,7,8-TCDD in Three 2011 High Resolution Cores Collected Near the Lister Avenue Site

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Estimated Cs-137 horizons are also shown



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-6a

Vertical Cs-137 Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

The dotted horizontal line represents the 1963 horizon
Depth plotted at midpoint of the sediment core interval

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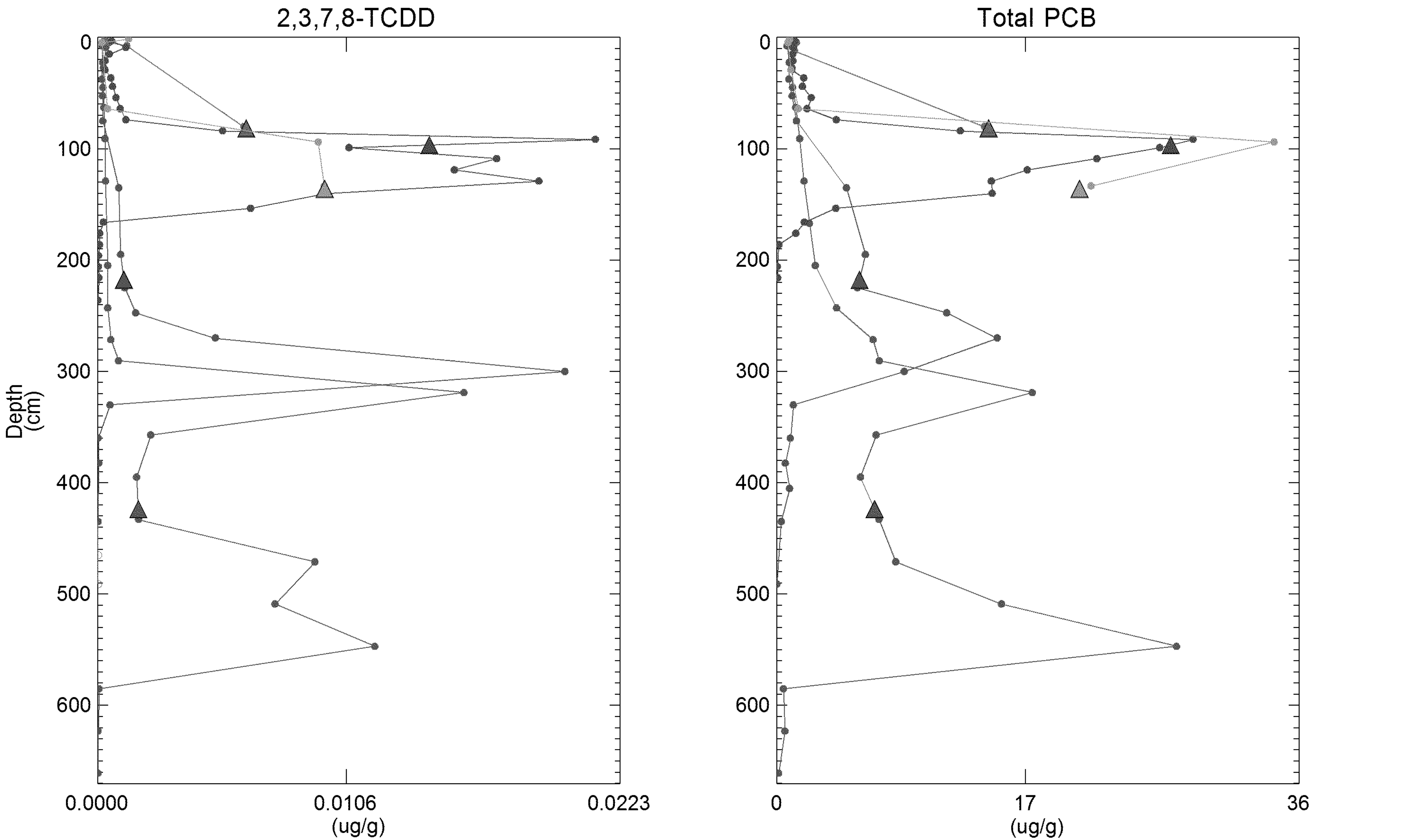

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

- RM 1.41
- RM 2.17
- RM 7.78
- RM 11.0
- RM 12.5

Figure 3-6b

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

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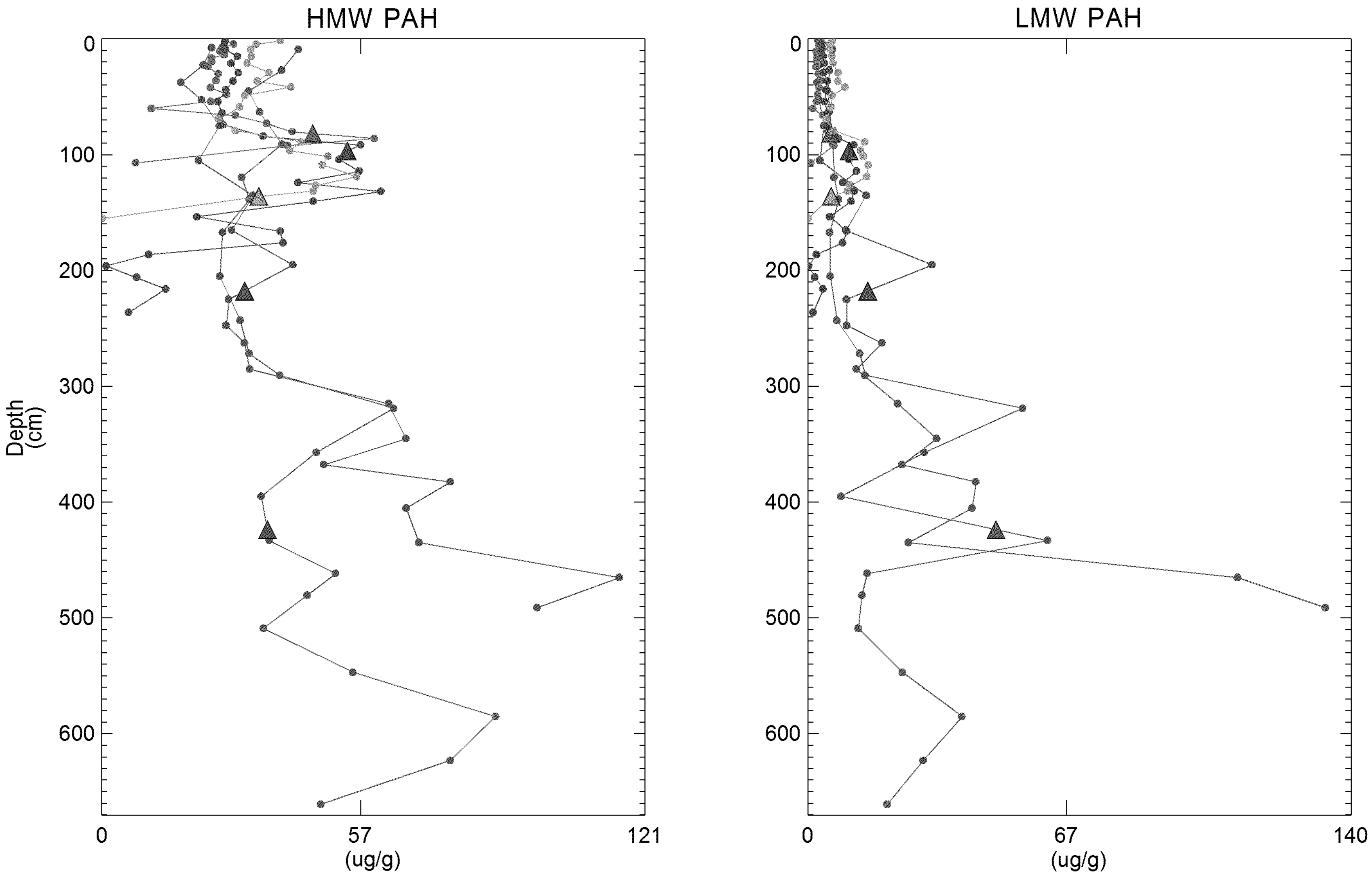

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-6c

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\verticalprofile_2005hrc _depth.pro
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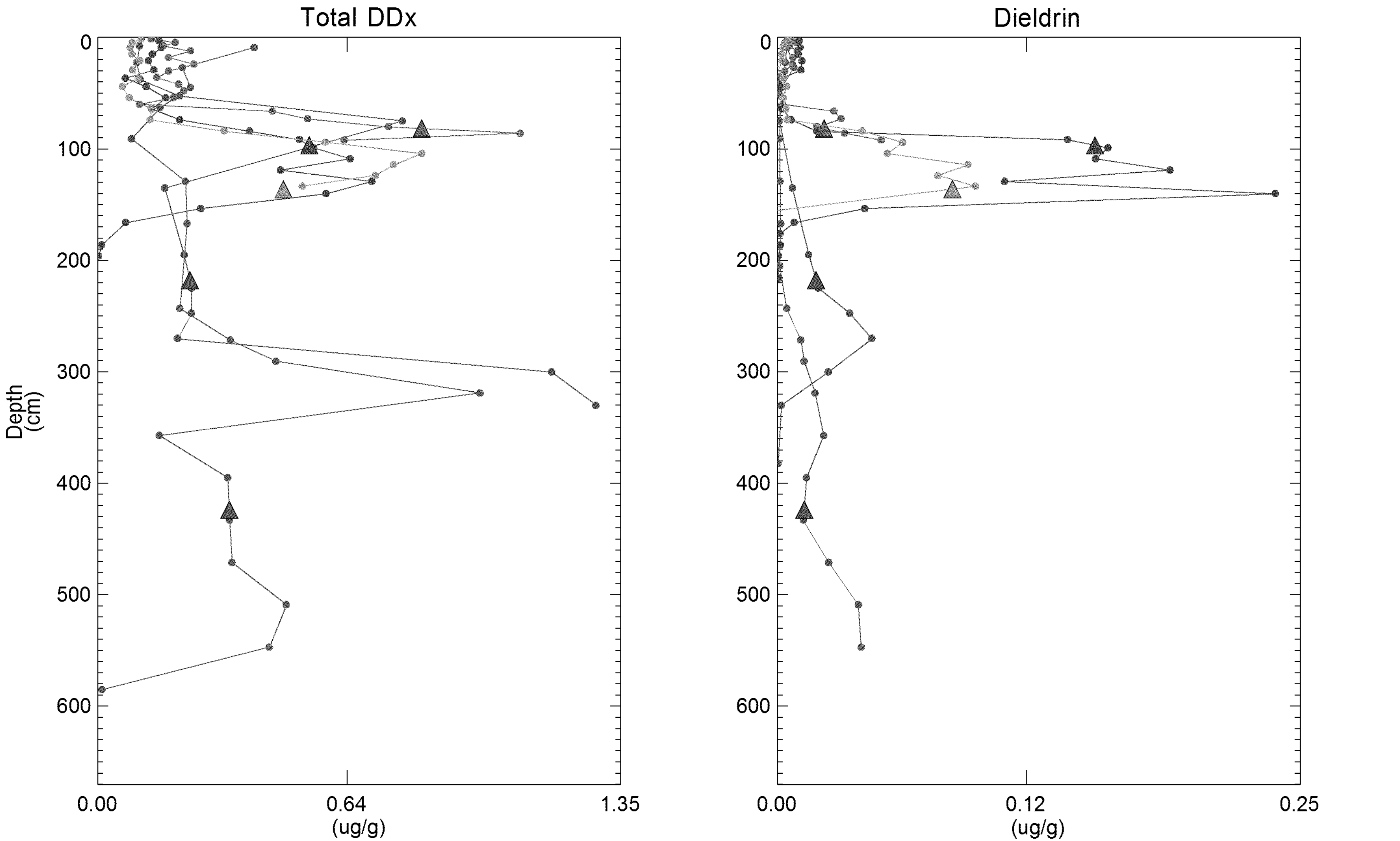

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

- RM 1.41
- RM 2.17
- RM 7.78
- RM 11.0
- RM 12.5

Figure 3-6d

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\verticalprofile_2005hrc _depth.pro
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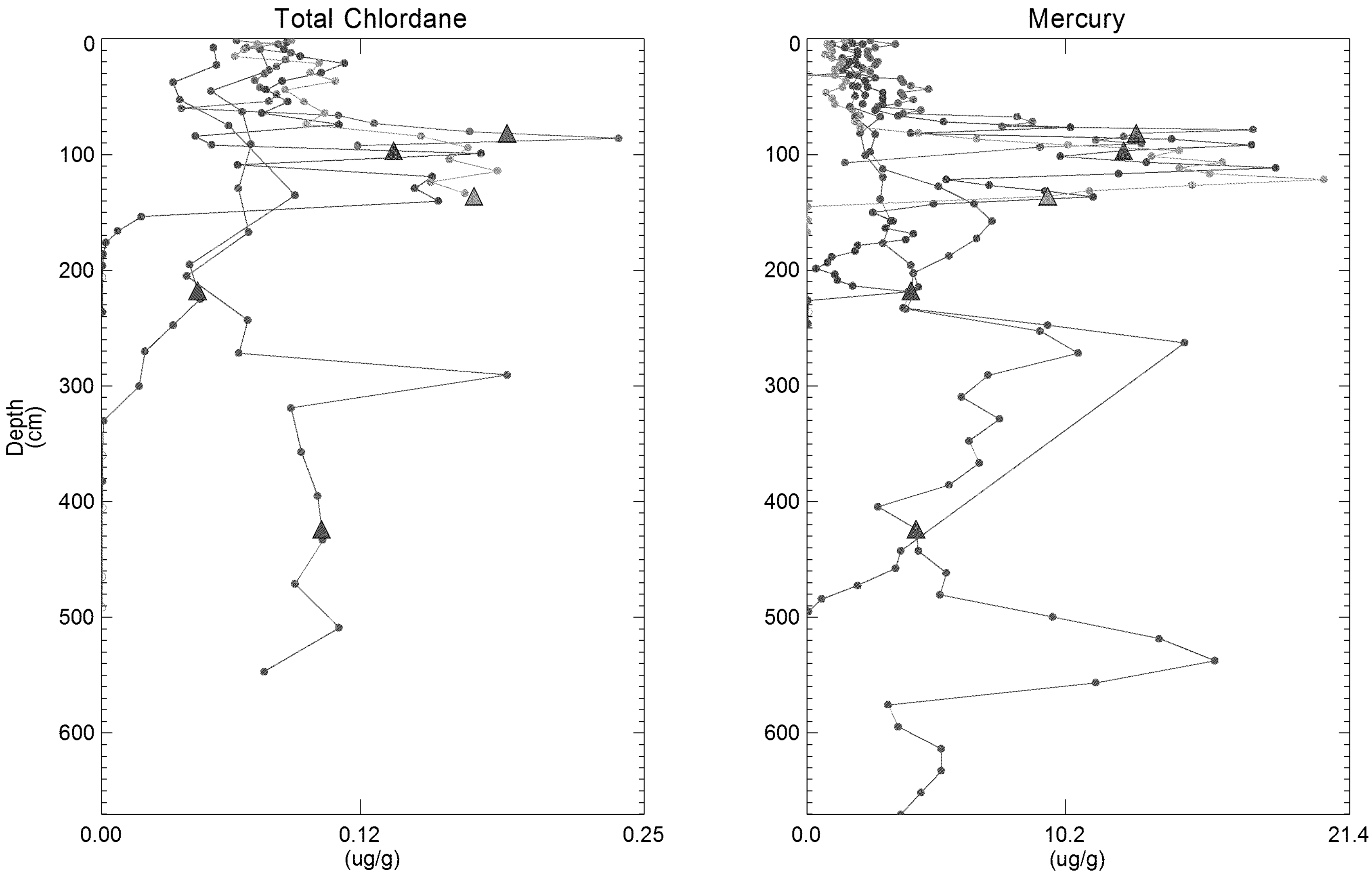

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-6e

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

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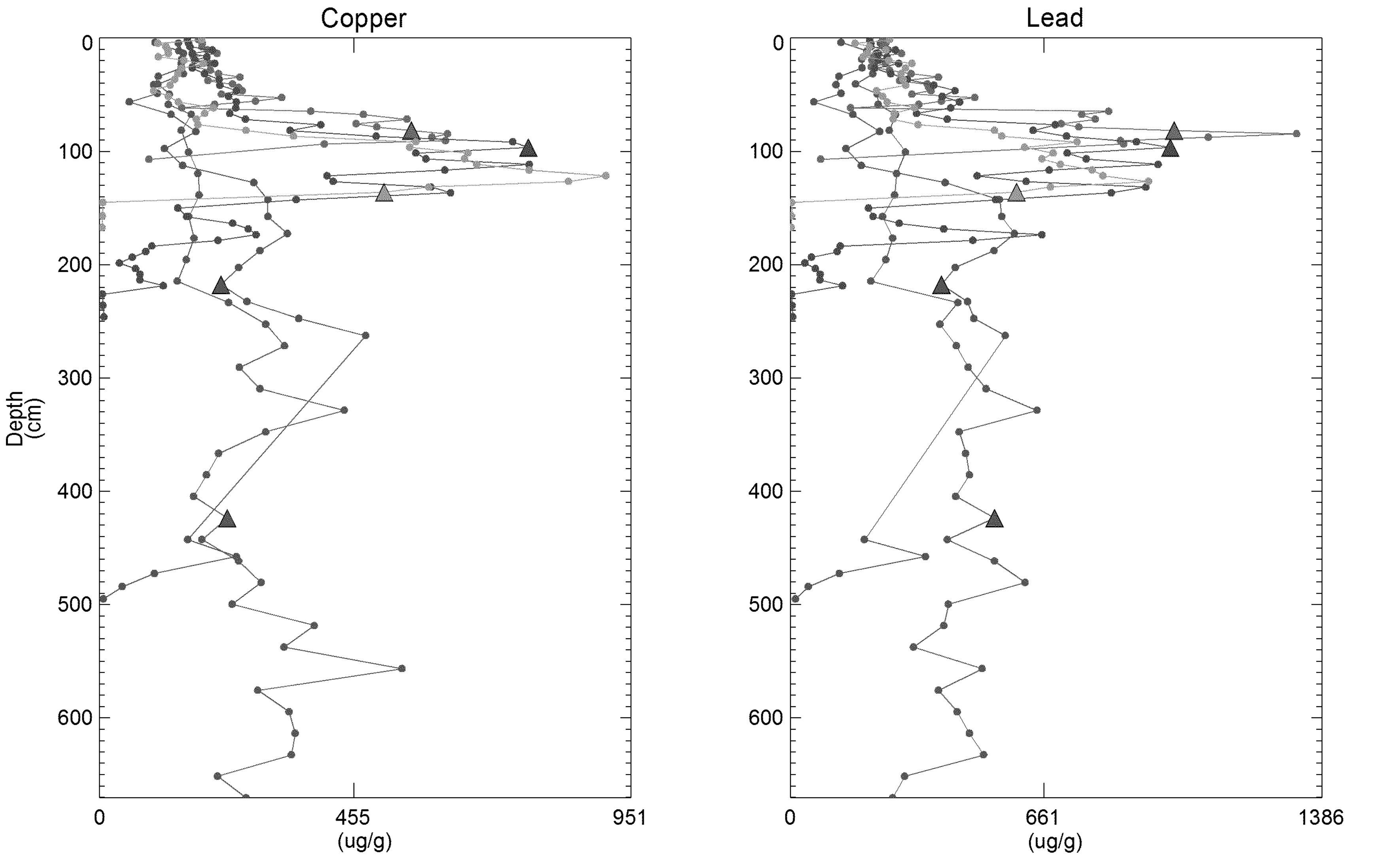

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-6f

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

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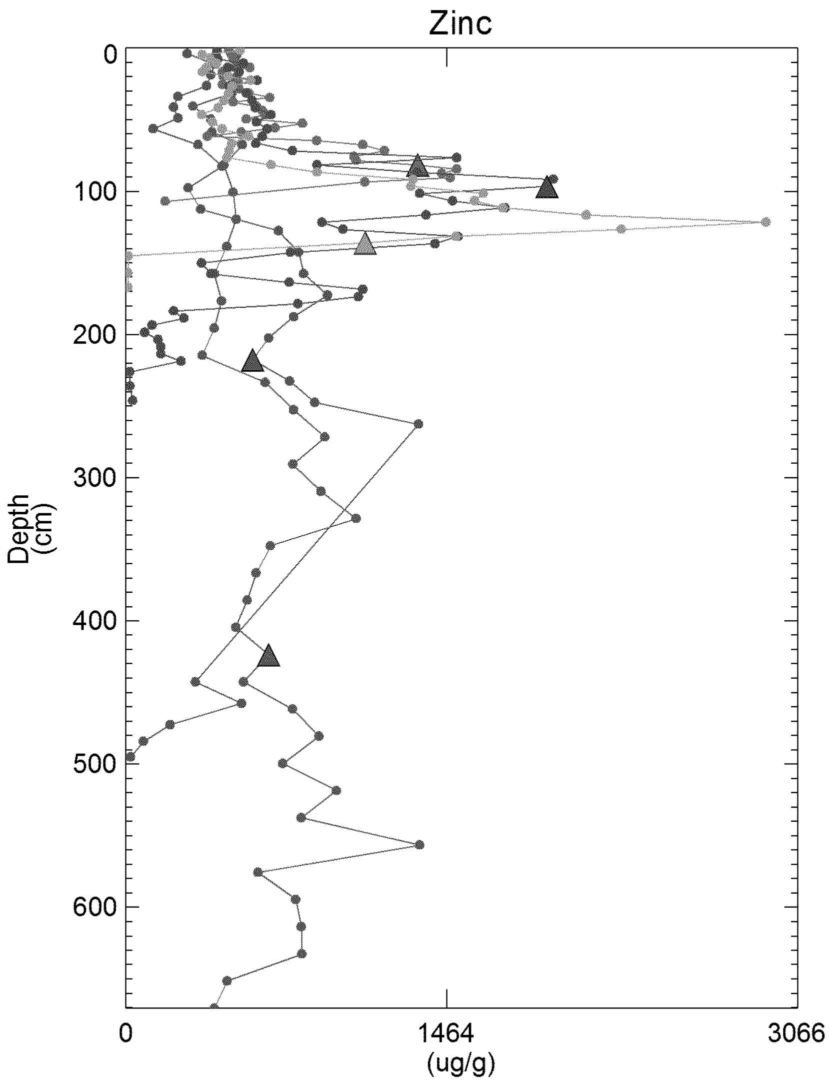

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

RM 1.41
RM 2.17
RM 7.78
RM 11.0
RM 12.5

Figure 3-6g

Vertical Contaminant Profiles in 2005 High Resolution Cores
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Depth plotted at midpoint of the sediment core interval
Triangles represent 1963 horizon at each location based on cesium depth profiles

SM - N:\Projects\Passaic_CPG\ANALYSIS\CSM\IDL\verticalprofile_2005hrc _depth.pro
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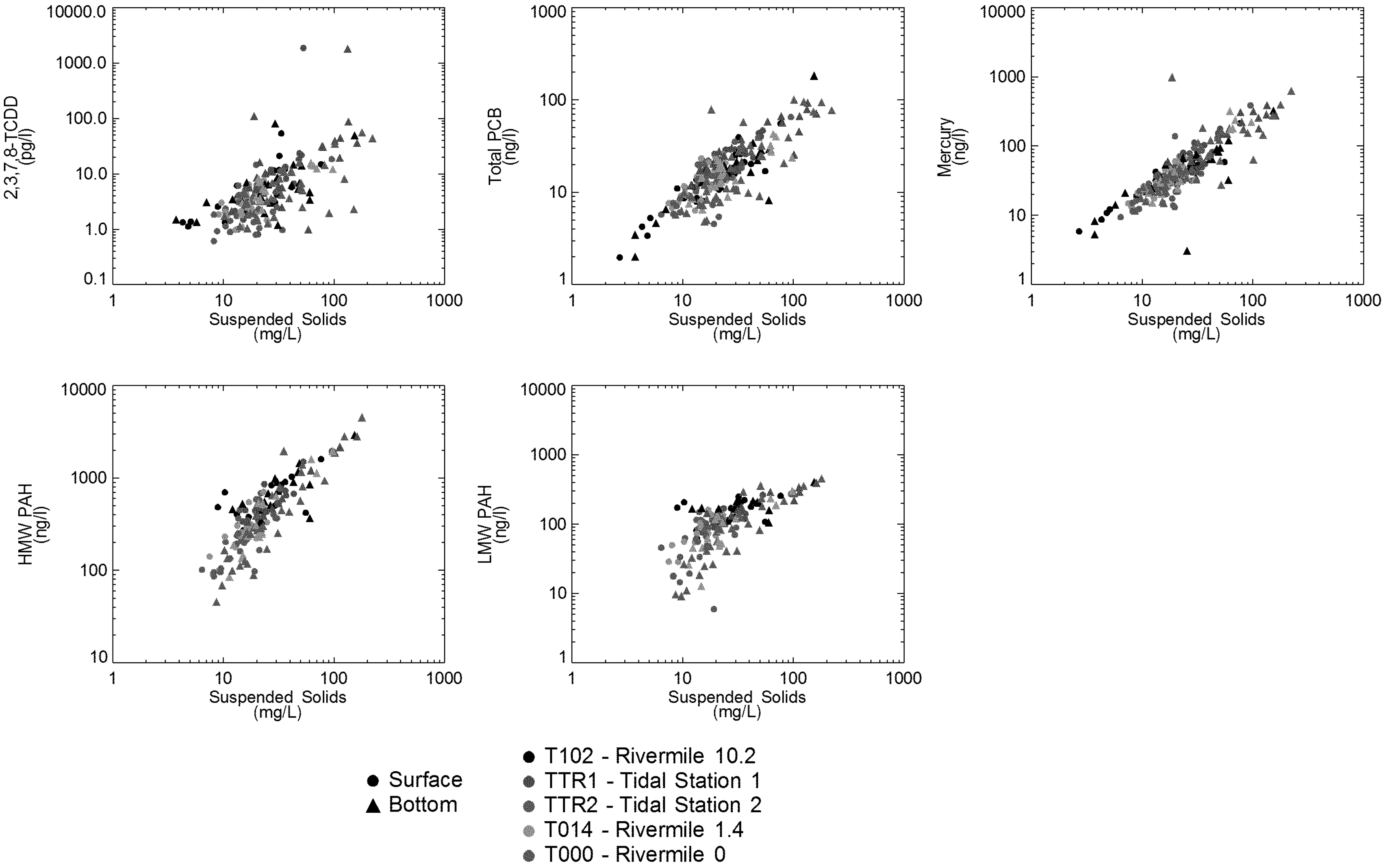

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-7

LPR Water Column Contaminant vs. Suspended Solids Concentration
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

ND samples have been excluded

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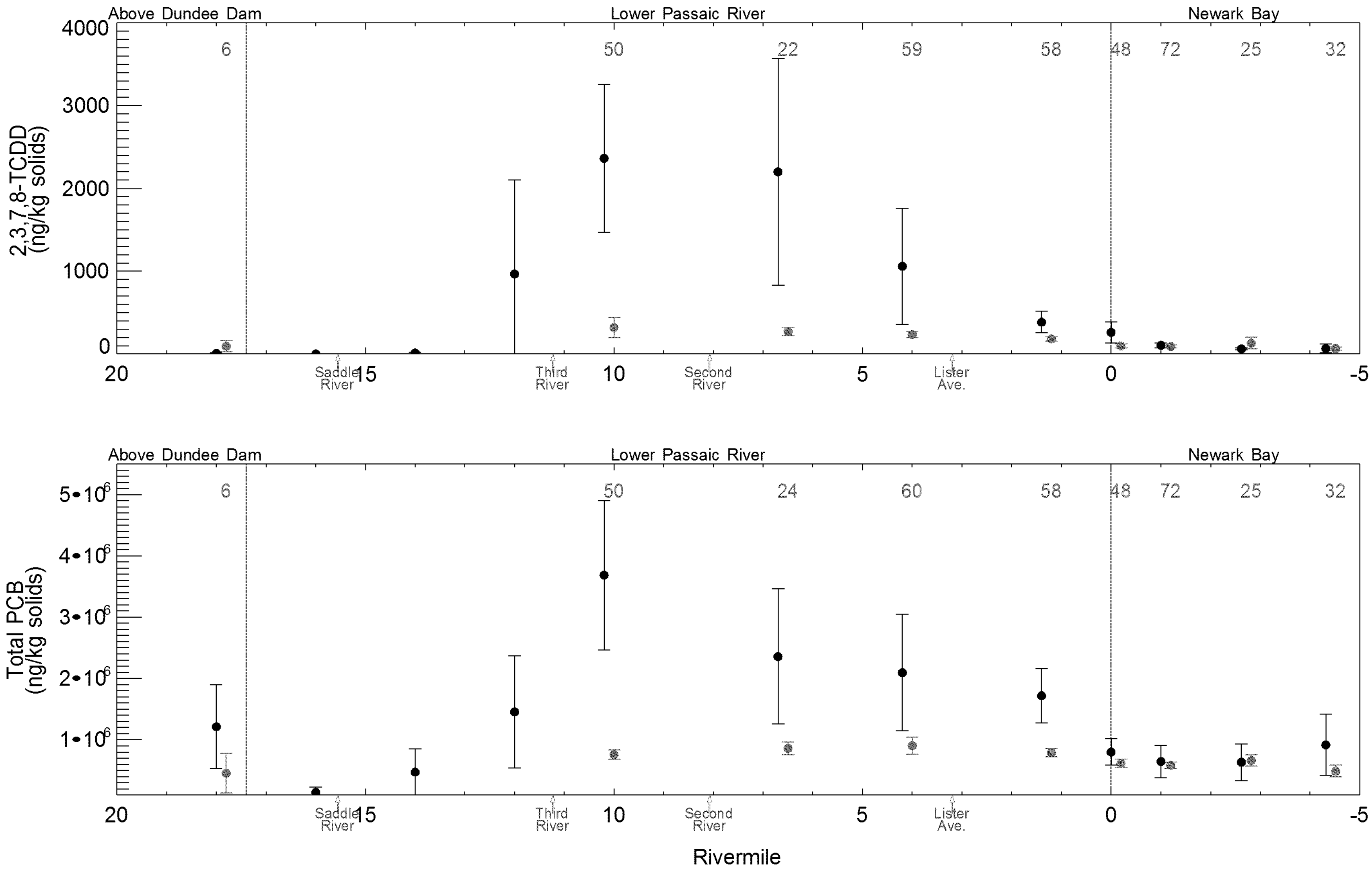

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-8a

2,3,7,8-TCDD and Total PCB Concentrations in Surface Sediments and Water Column of LPR

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean. NDs set to 1/2 detection limit. Water data is SSC normalized
Plots include only post 2000 data (listed in Table 3-1). Data binned spatially by water sampling locations
Numbers indicate sample counts in WC bin. 3 WC outlier samples have been removed for 2,3,7,8-TCDD

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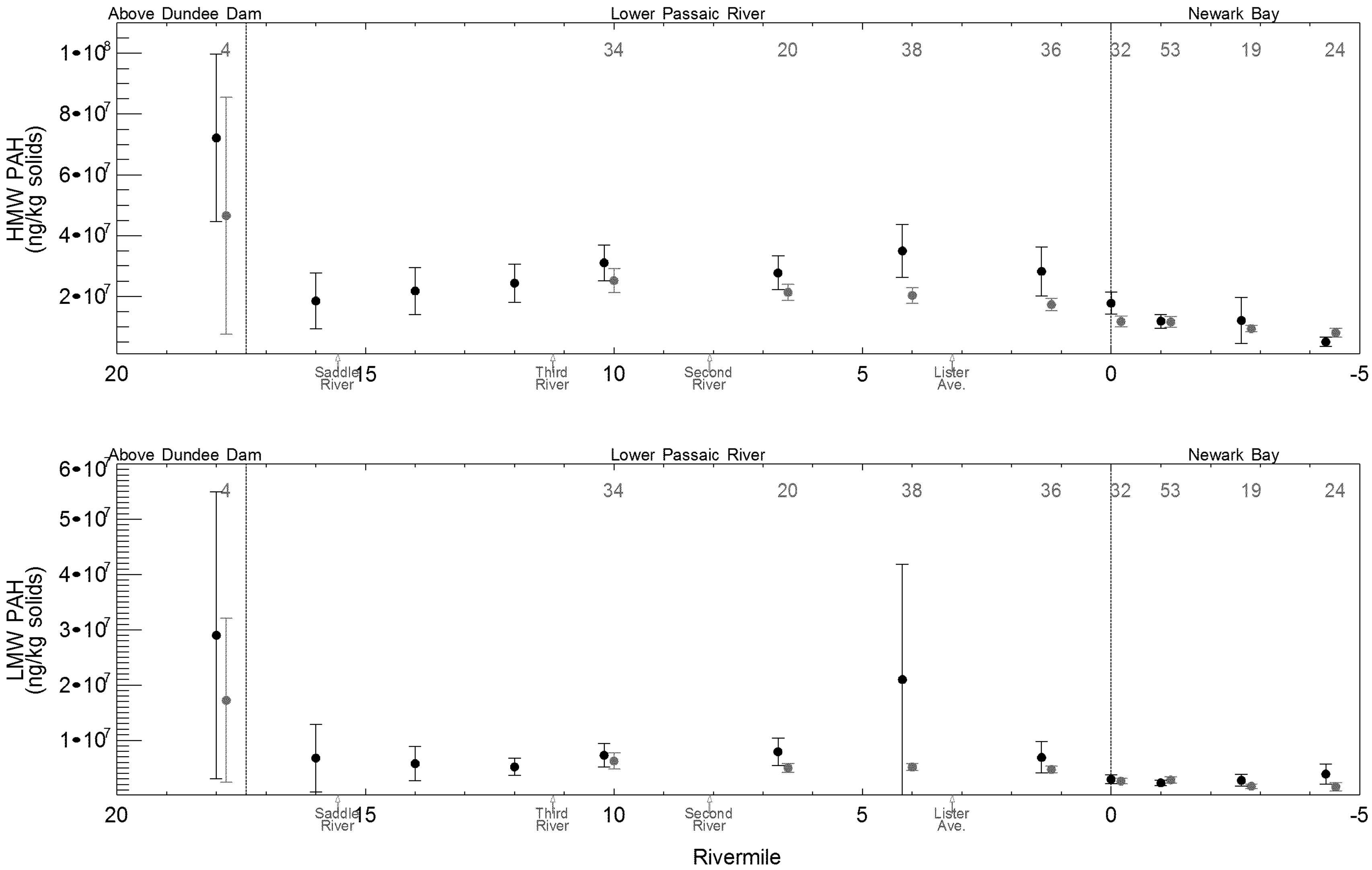

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-8b

HMW PAH and LMW PAH Concentrations in Surface Sediments and Water Column of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean. NDs set to 1/2 detection limit. Water data is SSC normalized
Plots include only post 2000 data (listed in Table 3-1). Data binned spatially by water sampling locations
Numbers indicate sample counts in WC bin

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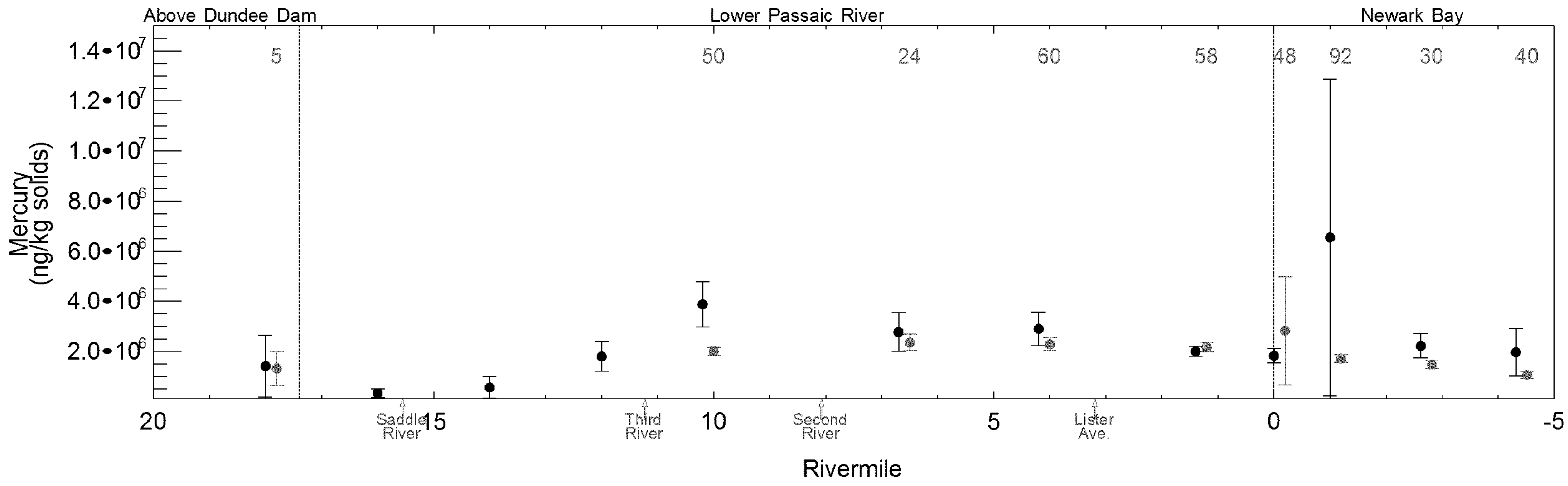

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

● Sediment
● Water

Figure 3-8c

Mercury Concentrations in Surface Sediments and Water Column of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean. NDs set to 1/2 detection limit. Water data is SSC normalized
Plots include only post 2000 data (listed in Table 3-1). Data binned spatially by water sampling locations
Numbers indicate sample counts in WC bin

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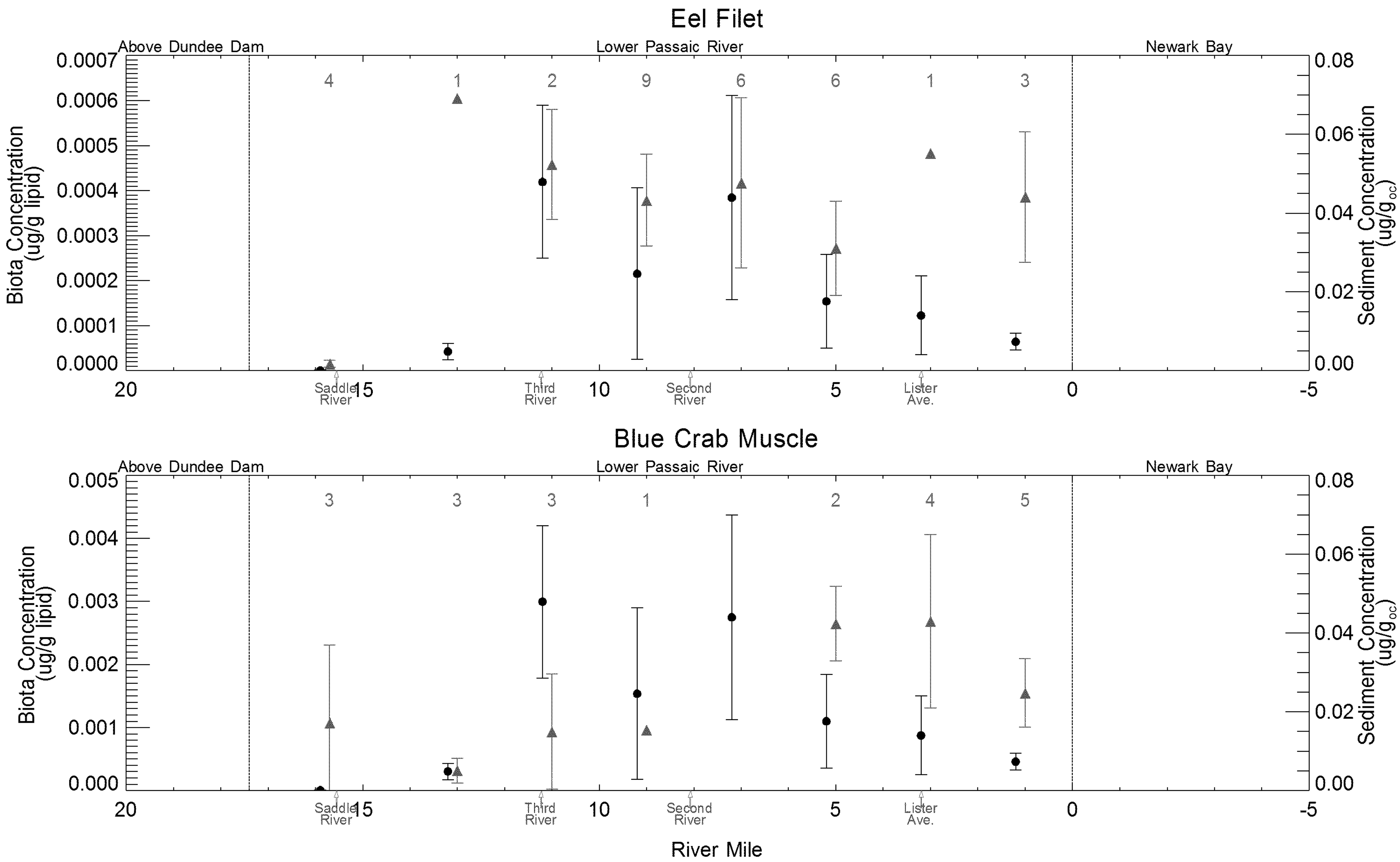

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-9a

2,3,7,8-TCDD Concentrations in Surface Sediments and Biota of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

● Sediment
▲ Biota

Plots include only post 2000 data (listed in Table 3-1). Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean
Plots includes all samples with a bottom slice depth of 6 inches or less
Biota data from 2009 Passaic WindWard fish sampling program. Numbers indicate sample counts in WC bin

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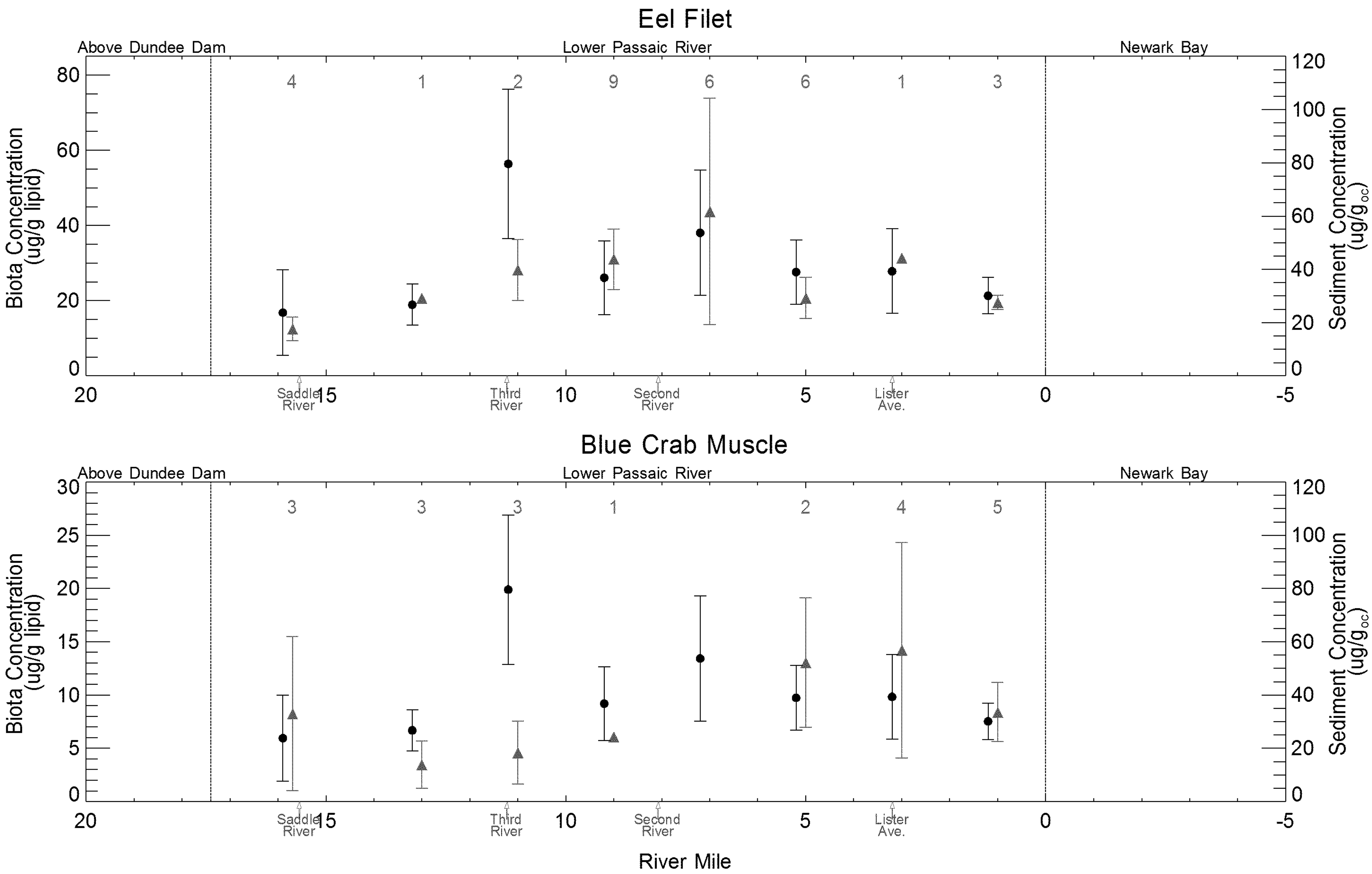

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

● Sediment
▲ Biota

Figure 3-9b

Total PCB Concentrations in Surface Sediments and Biota of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean
Plots includes all samples with a bottom slice depth of 6 inches or less
Biota data from 2009 Passaic WindWard fish sampling program. Numbers indicate sample counts in WC bin

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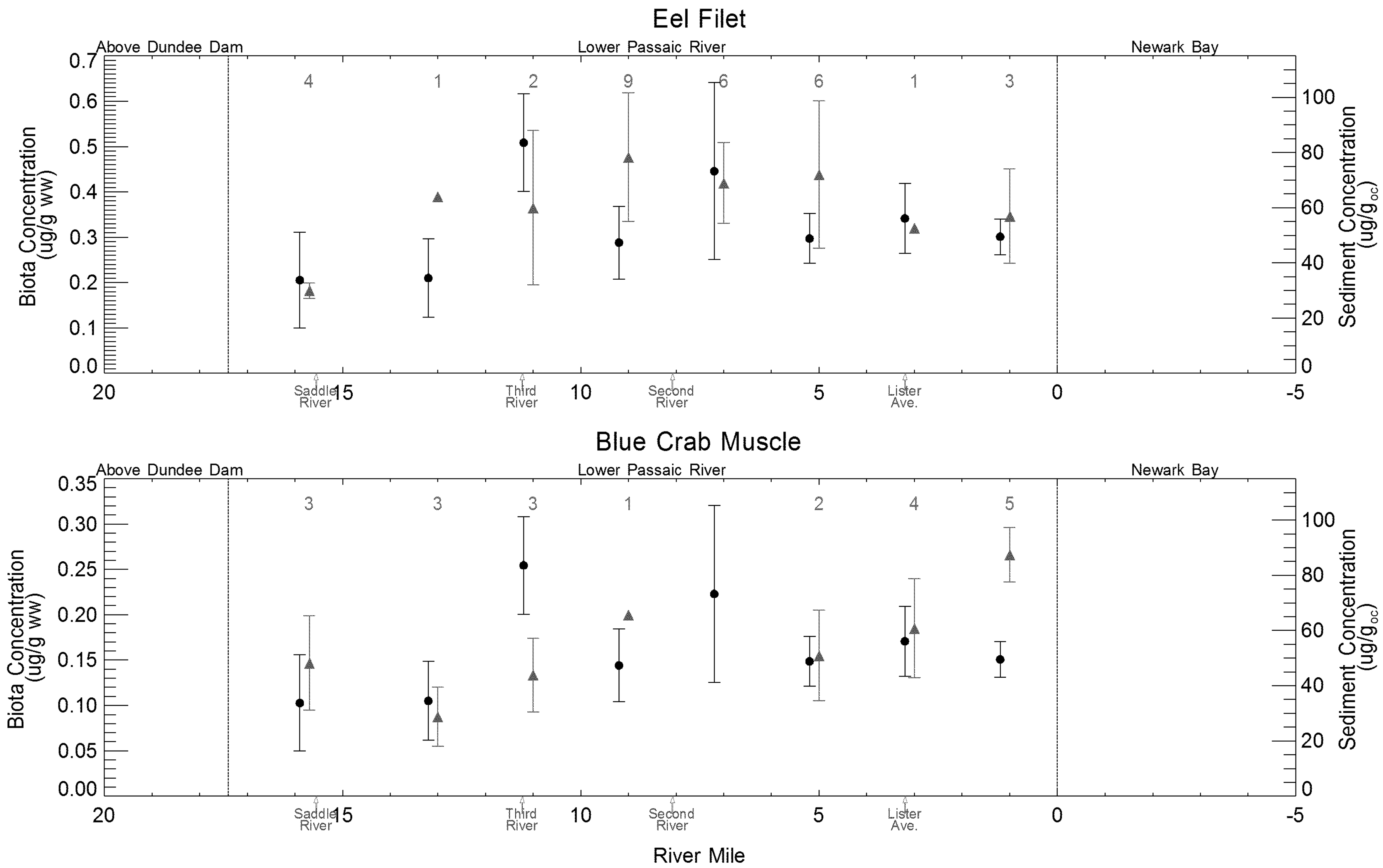

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-9c

Mercury Concentrations in Surface Sediments and Biota of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). Tributary data excluded. Error bars depict limits of +/- 2 standard errors of the mean
Plots includes all samples with a bottom slice depth of 6 inches or less
Biota data from 2009 Passaic WindWard fish sampling program. Numbers indicate sample counts in WC bin

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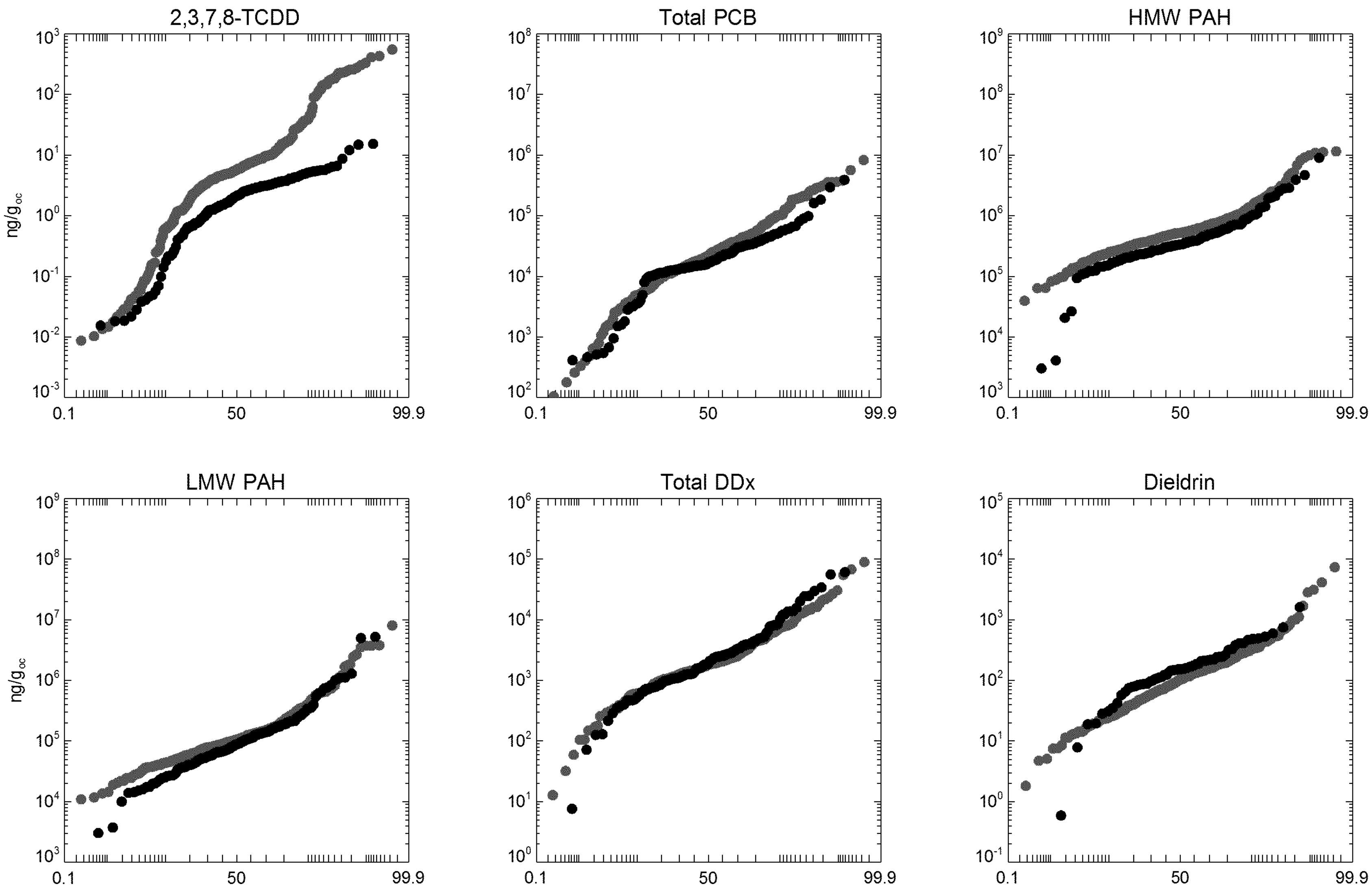

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-10a

Probability Distribution of Surface Contaminant Concentrations
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded

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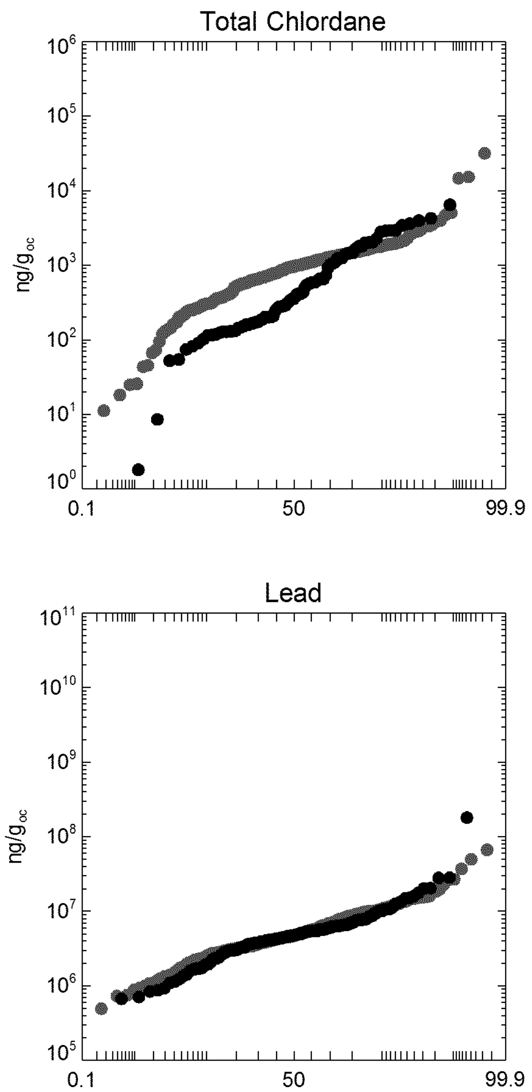

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

● LPR
● Outside LPR

Figure 3-10b

Probability Distribution of Surface Contaminant Concentrations
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND samples have been excluded

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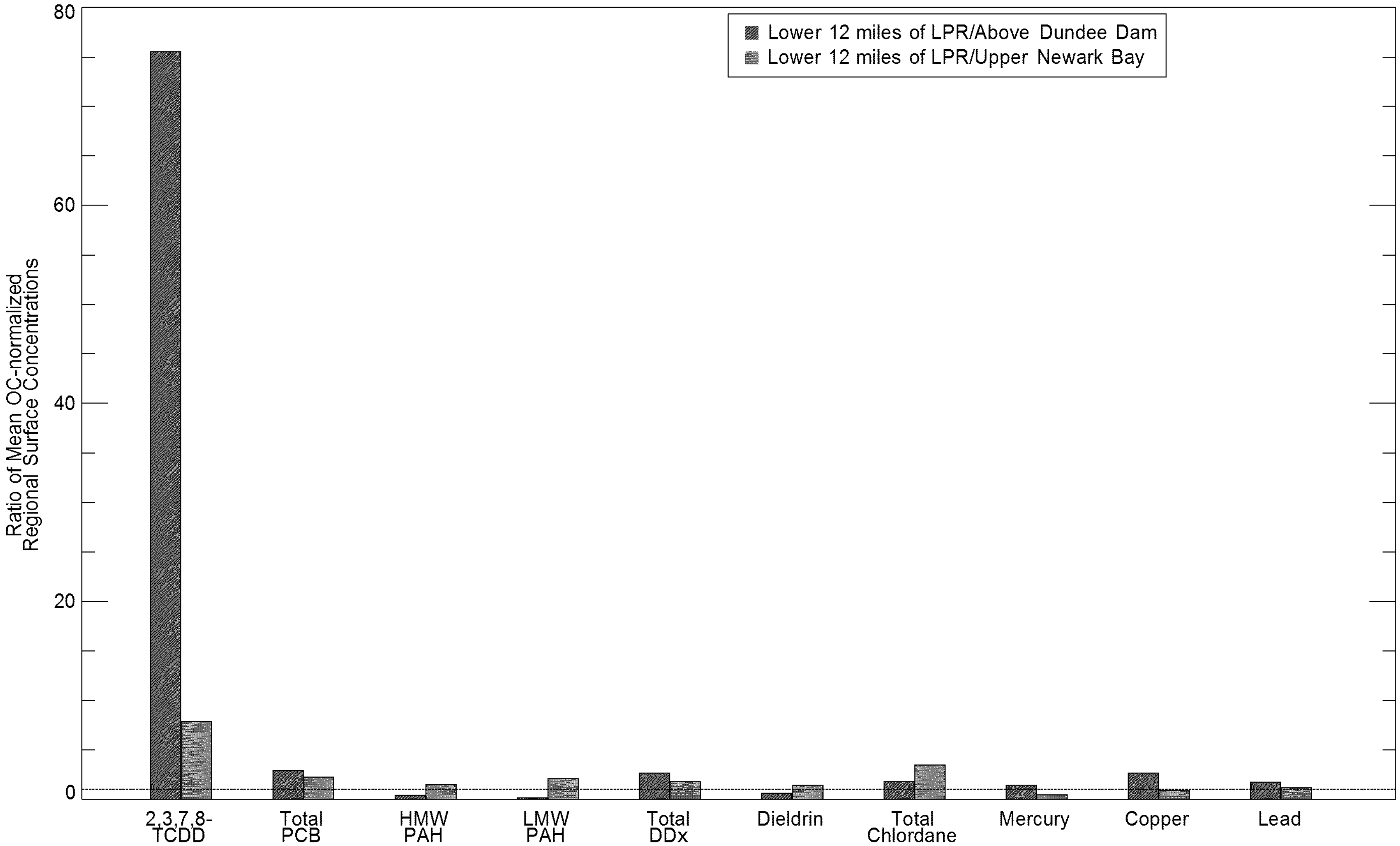

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-11

Ratios of Mean Contaminant Levels in Surface Sediments in LPR and Nearby Regions
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

ND samples have been removed

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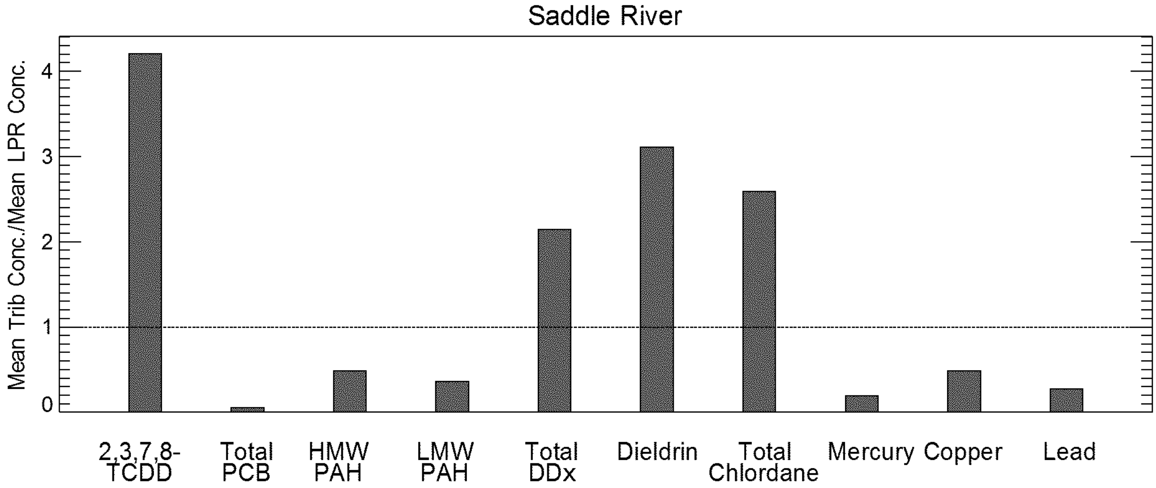

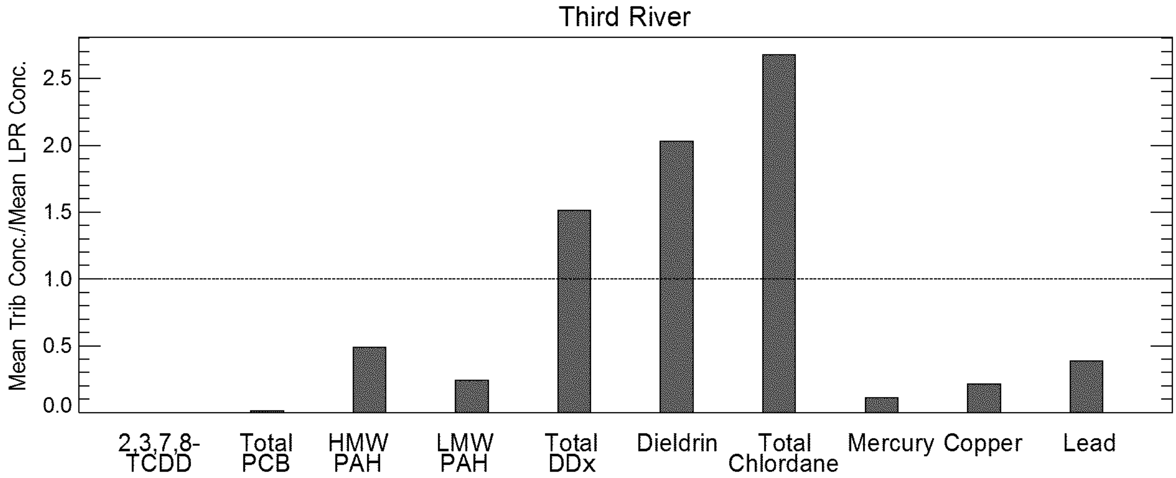

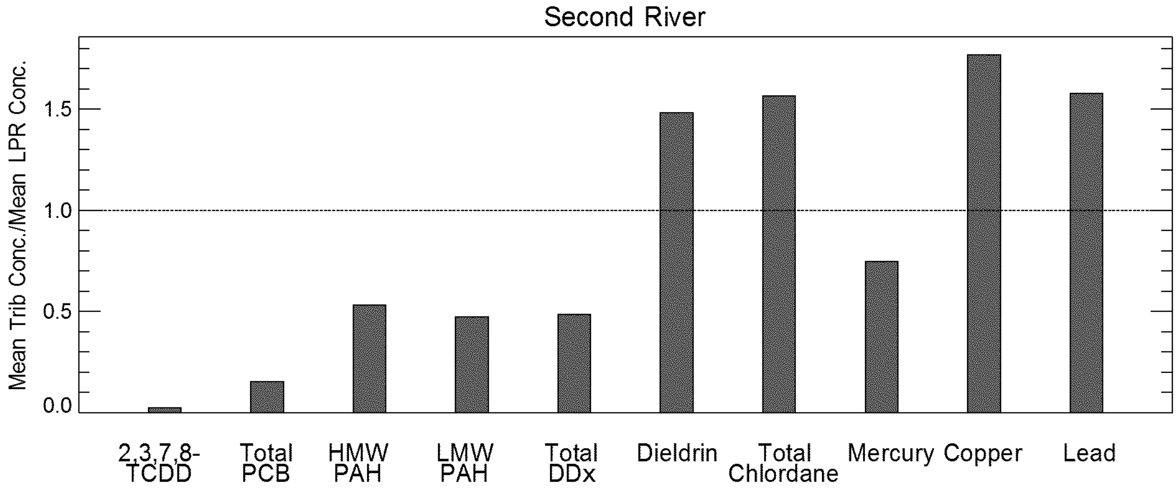

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 3-12

Ratios of Average Contaminant Concentrations in Surface Sediments of Tributaries and LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Each bar represents ratio of mean OCN contaminant concentration above HOT in corresponding tributary to mean OCN contaminant concentration within 0.2 miles of confluence in LPR
Trib samples below HOT have been excluded due to potential tidal influences
ND samples removed have been excluded

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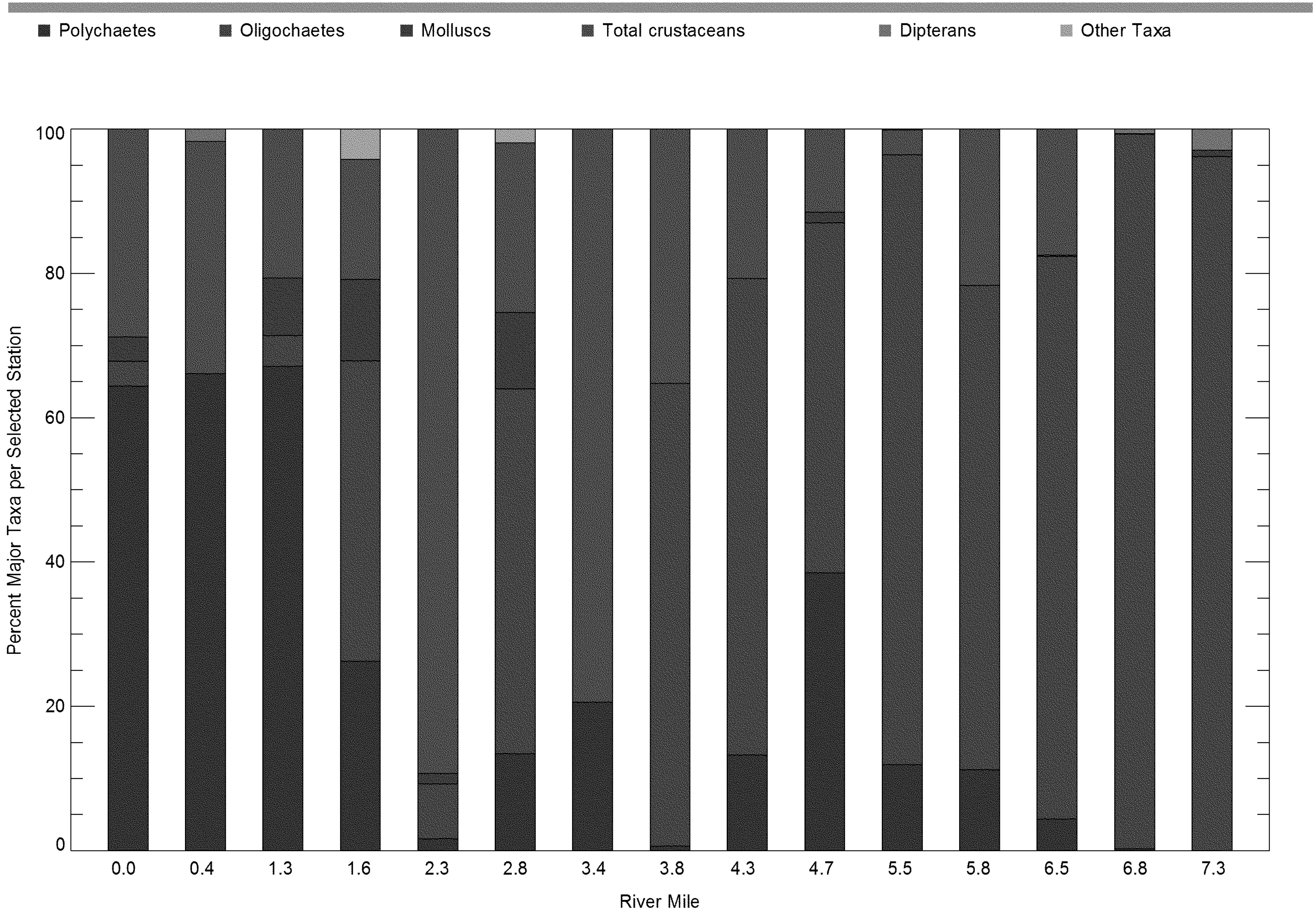
PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-1
General Ecological CSM for the LPRSA
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 4-2
Ecological Food Web
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-3

Major Taxonomic Benthic Invertebrates in the Lower Portion of LPRSA during Fall 2009 Survey
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Source: Windward (2011b)

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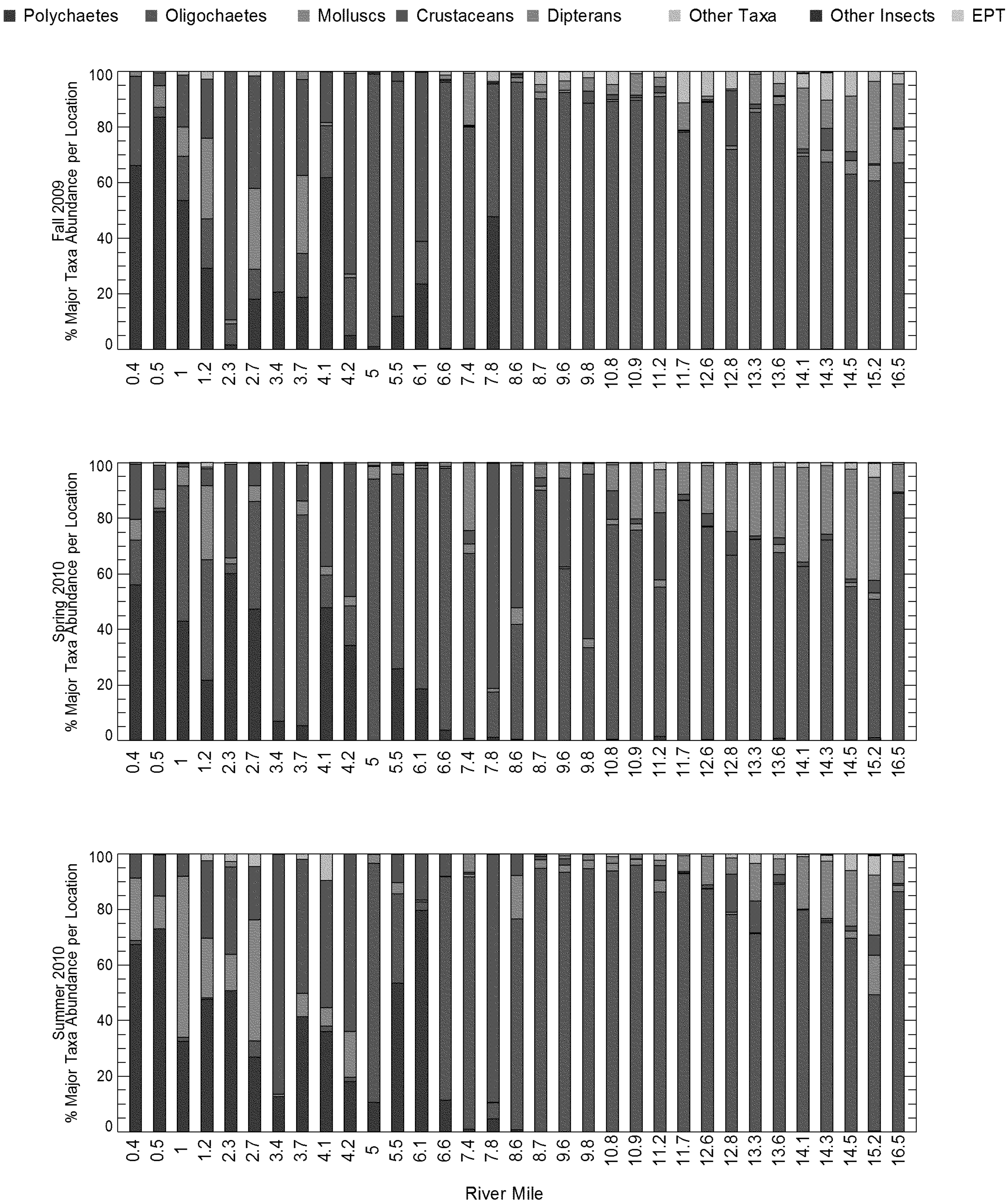

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-4

Comparison of Major Benthic Invertebrate Taxonomic Groups during 2009 and 2010 Surveys
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

EPT - Ephemeroptera, Plecoptera, and Trichoptera
Source: Windward (2012a)

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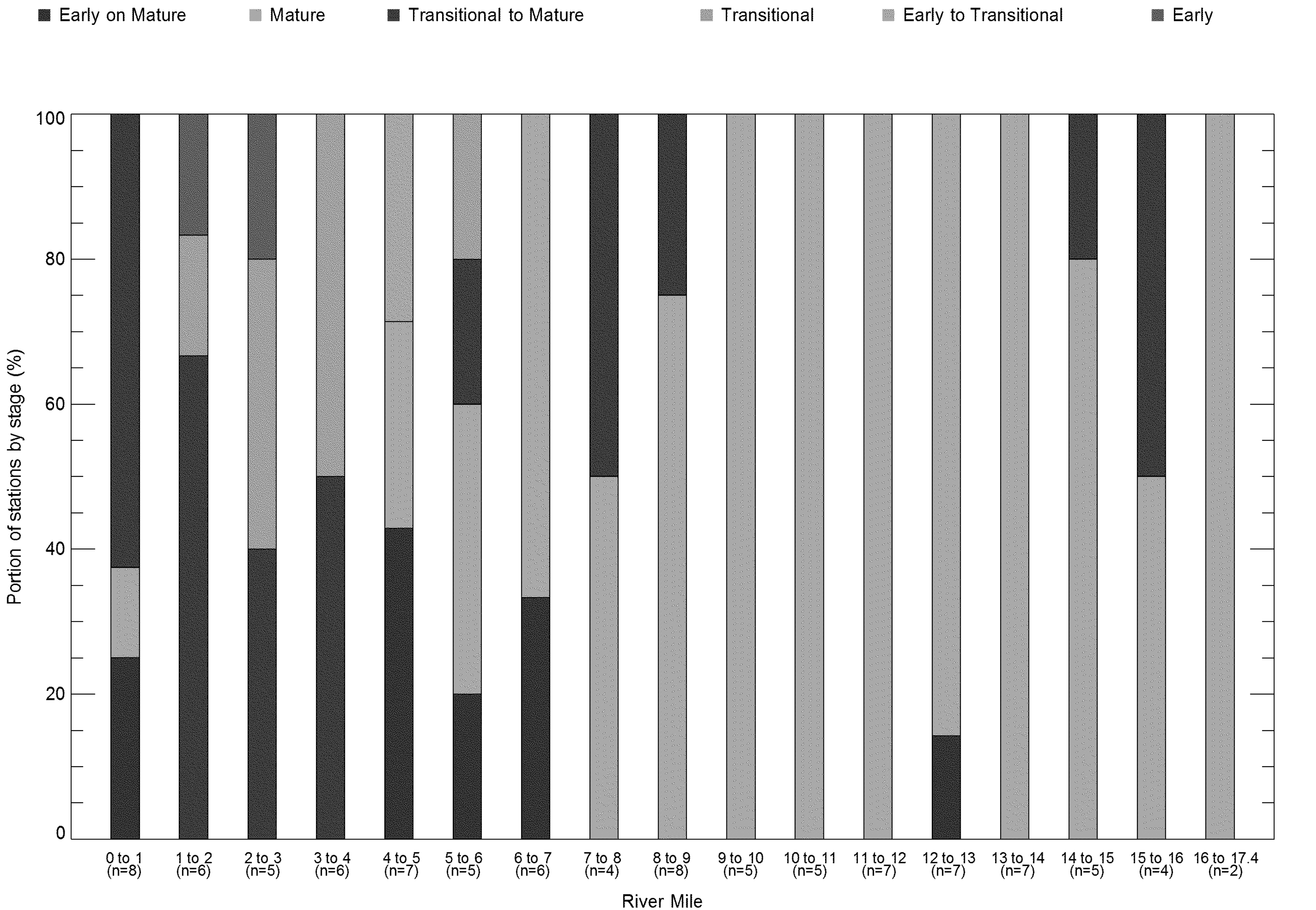

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-5

Distribution of Benthic Invertebrate Community Successional Stages by River Mile
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Source: Windward (2011b), figure not previously published

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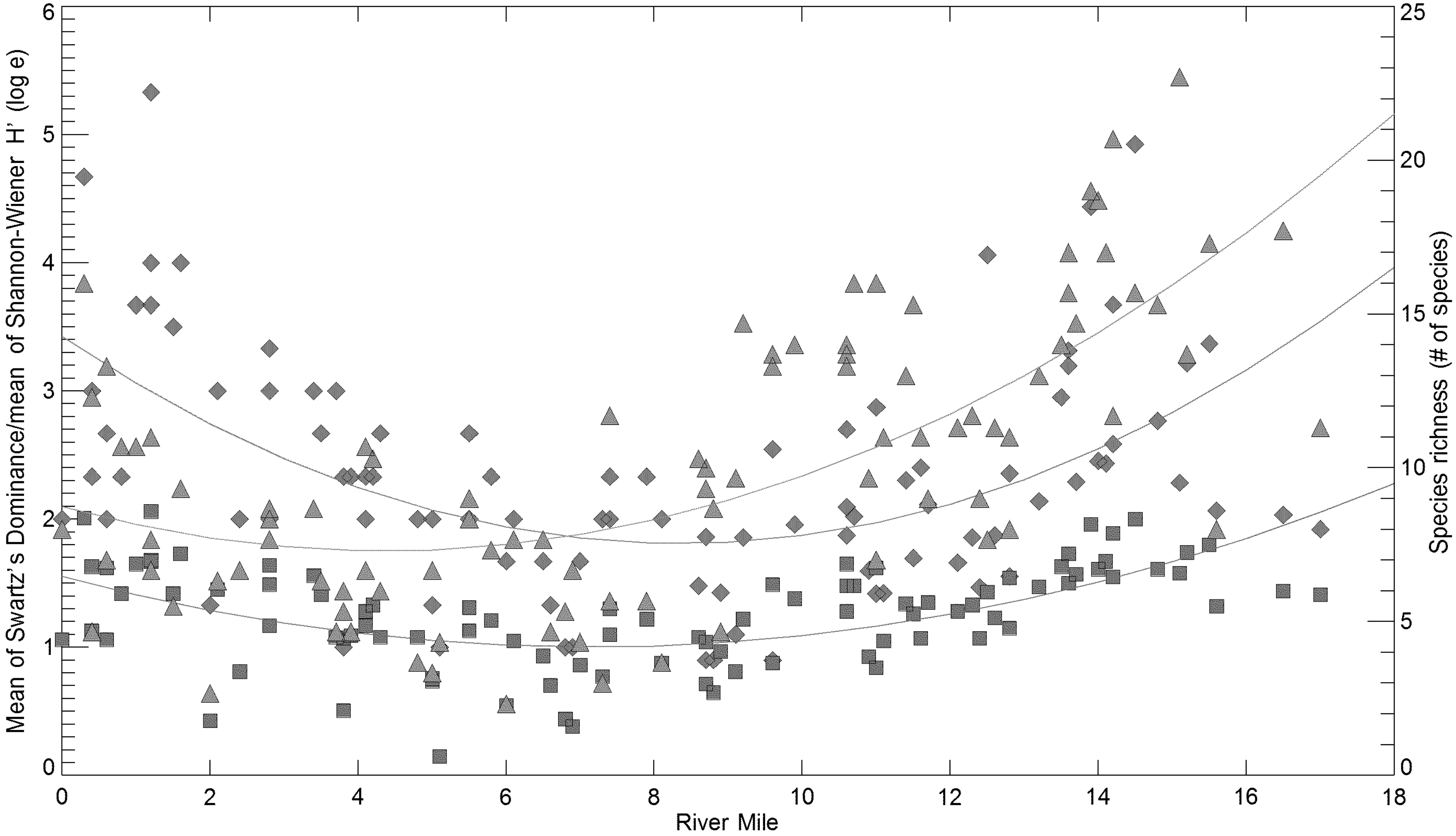
Source: Windward, in prep

Figure 4-6
LPRSA Salinity Zones Based on Benthic Organisms
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

◆ Mean of Swartz's Dominance
■ Mean of Shannon-Wiener H' (log e)
▲ Richness

Figure 4-7

Benthic Community Diversity Indices and Species Richness by River Mile
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Source: Windward, in prep

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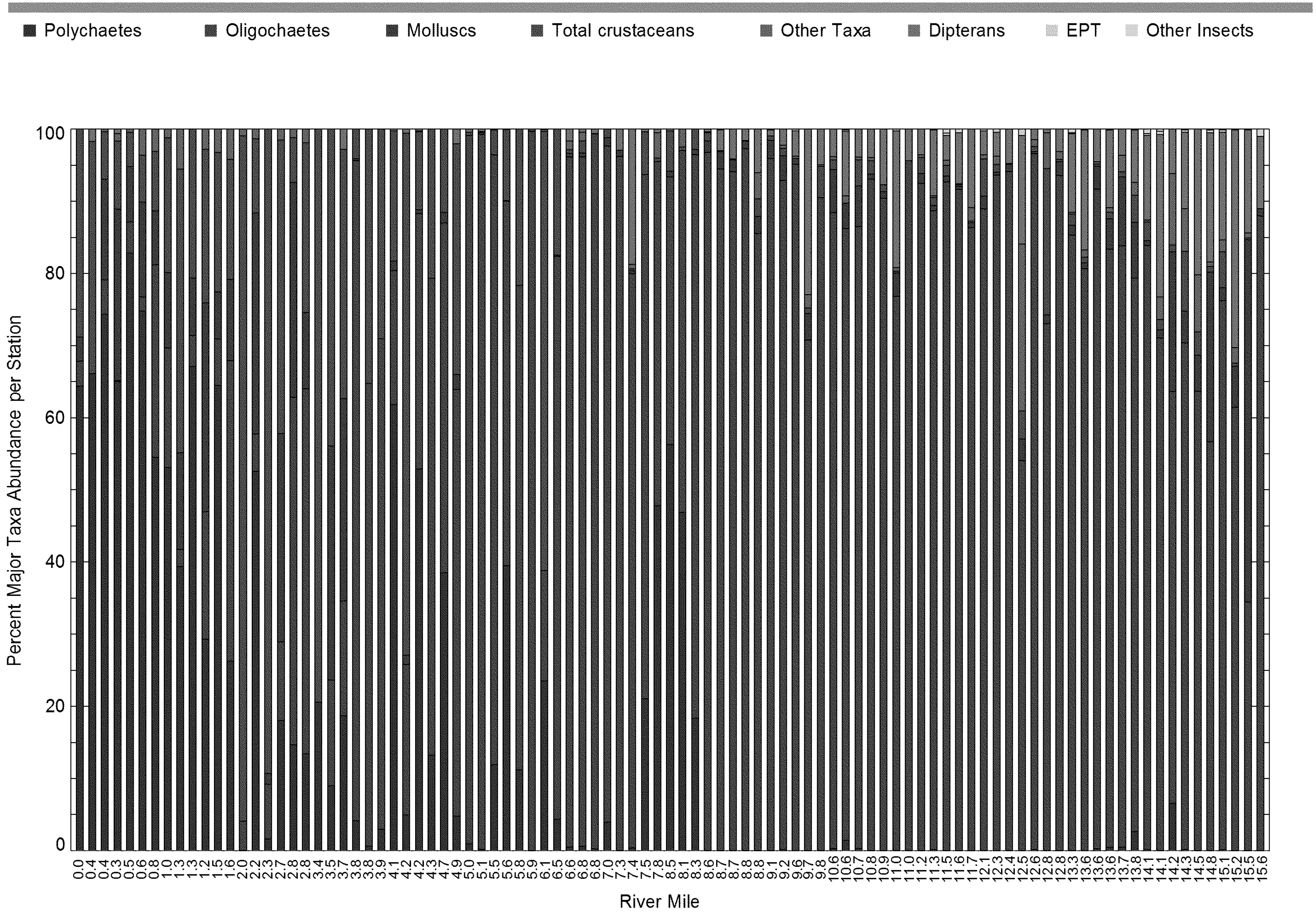

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-8

Benthic Community Percent Major Taxa by Station
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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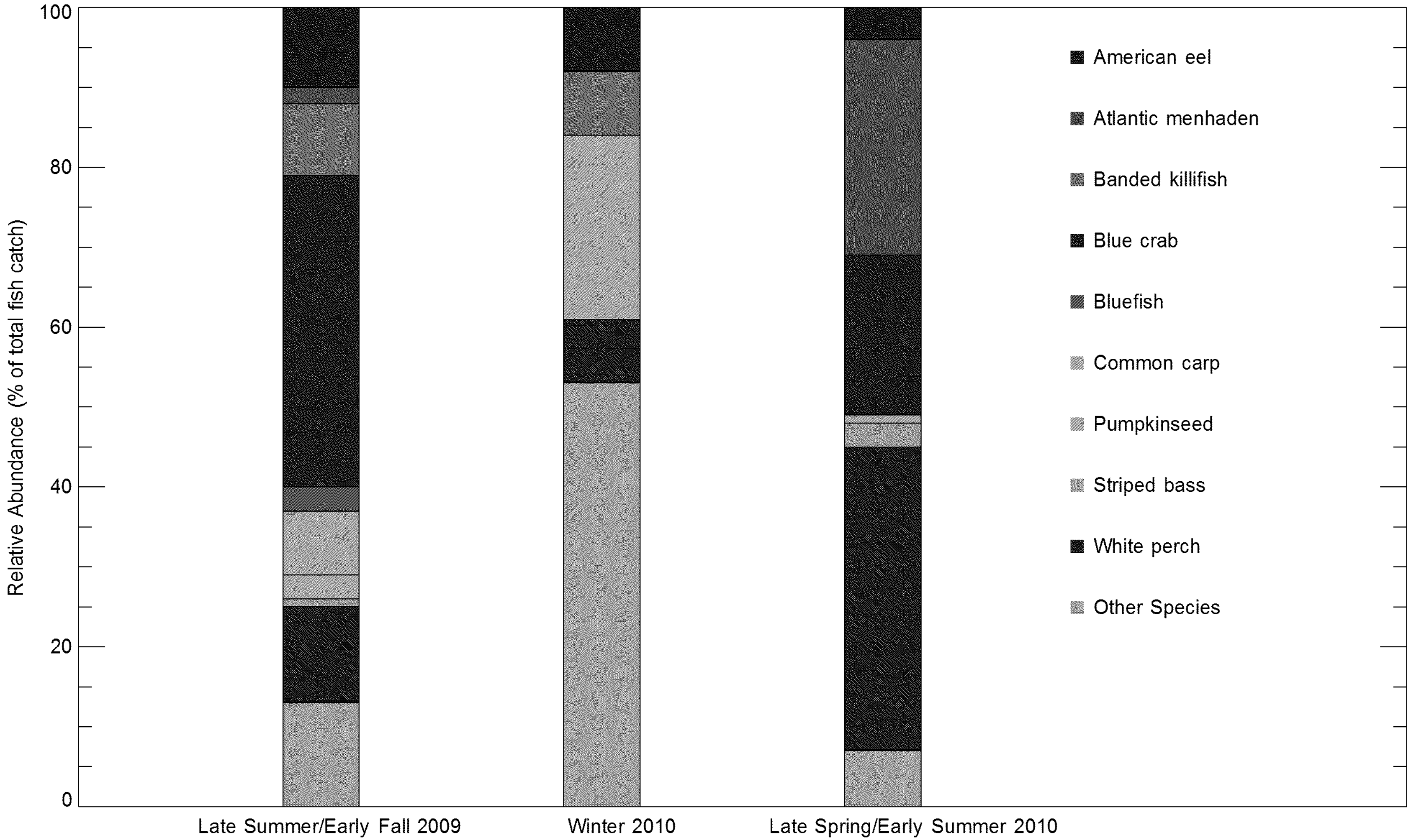

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-9

Relative LPRSA Fish/Crab Species Abundance
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

1. Relative abundance provided for fish/crab caught by methods used for fish community survey (gill nets, traps, trotlines, and electrofishing); other methods during the 2010 field efforts (cast nets and seines) not included.
2. Late summer/early fall 2009 data limited to include first two attempts for each method and only locations reoccupied during the winter and late spring/early summer surveys

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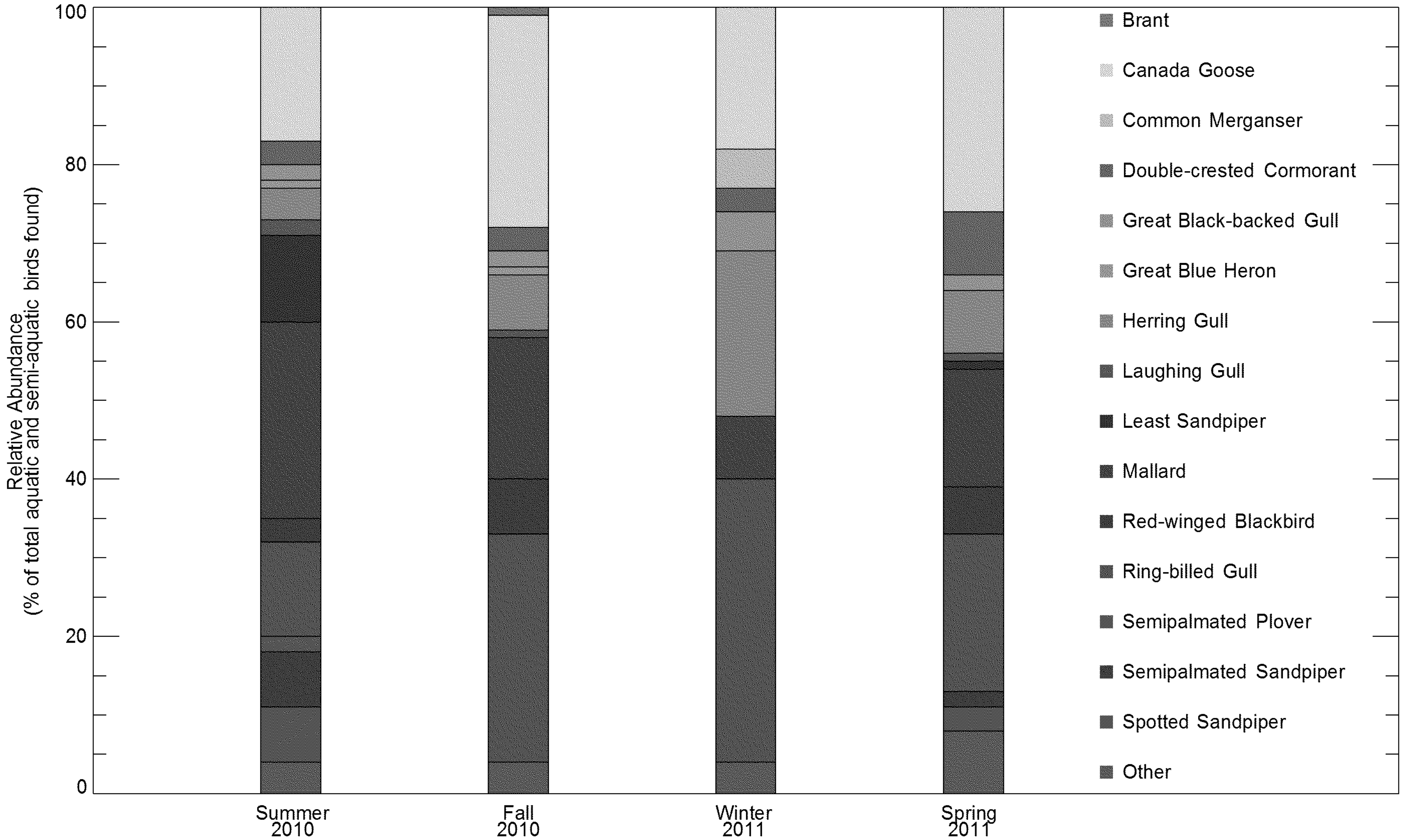
Note:
Shallow flat areas for ecological receptors are those areas where the river bottom slope is ≤ 6° and the depth is ≥ -4.5 ft NGVD29 (i.e., -2 ft MLLW), based on the 2007 bathymetric survey conducted by Gahagan & Bryant Associates, Inc. (GBA). Areas of the LPRSA not covered by the GBA survey (i.e., southeast Kearney Point, PM 16.5 to RM 17.4, and some nearshore shallows) have been extrapolated either from contours derived from the GBA baythmetry data, or from NOAA data (specifically Kearney Point). Mudflats are defined as areas with silt and/or sand river bottom. Gravel flats consist of coarser material. Surface texture was delineated by Aqua Survey, Inc. in its 2005 Geophysical Survey. All of Kearney Point is assumed to be sand or silt based on field experience.

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-10
Shallows and Shallow Flats in the Lower Passaic River Study Area
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-11
Relative Avian Species Abundance
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-12a

LPRSA Land Use and Shoreline Features

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 4-12b
LPRSA Land Use and Shoreline Features
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-12c
LPRSA Land Use and Shoreline Features
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-12d

LPRSA Land Use and Shoreline Features

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 4-12e
LPRSA Land Use and Shoreline Features
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 4-12f
LPRSA Land Use and Shoreline Features
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 4-13
General Human Health CSM for the LPRSA
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-1
Computed Variation of Salinity Intrusion as a Function of River Discharge
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-2

Velocity, Salinity, and TSS at Lower Passaic River Stations from the Fall PWCM Program

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-3
Conceptual Regime Figure
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

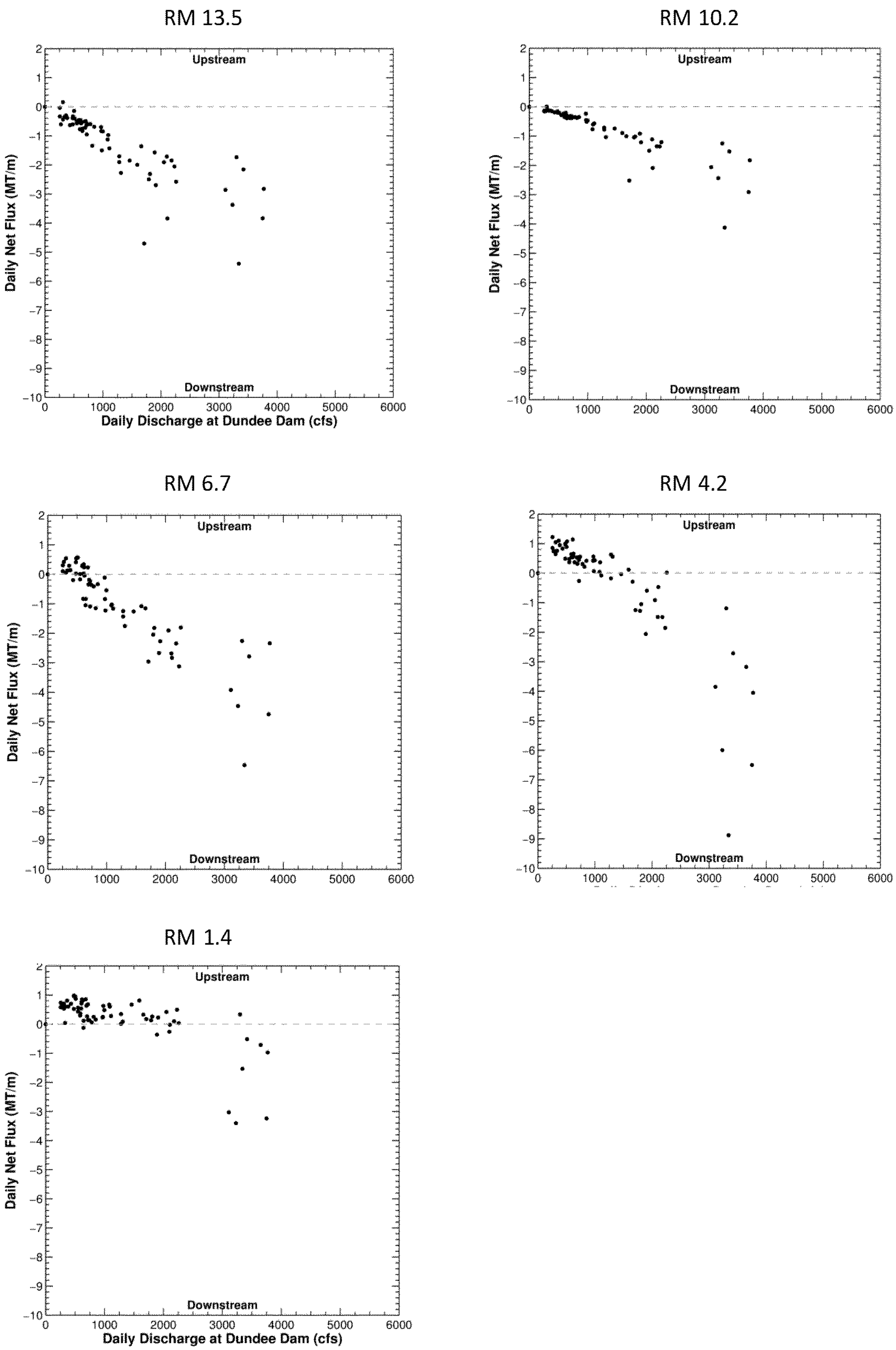


Figure 5-4

Daily Net Flux as a Function of Daily Discharge (from Fall 2009 PWCM Data)

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Positive values indicate upstream flux and negative values indicate downstream flux.

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-5
Lower Passaic River Flux Calculations and Mooring Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

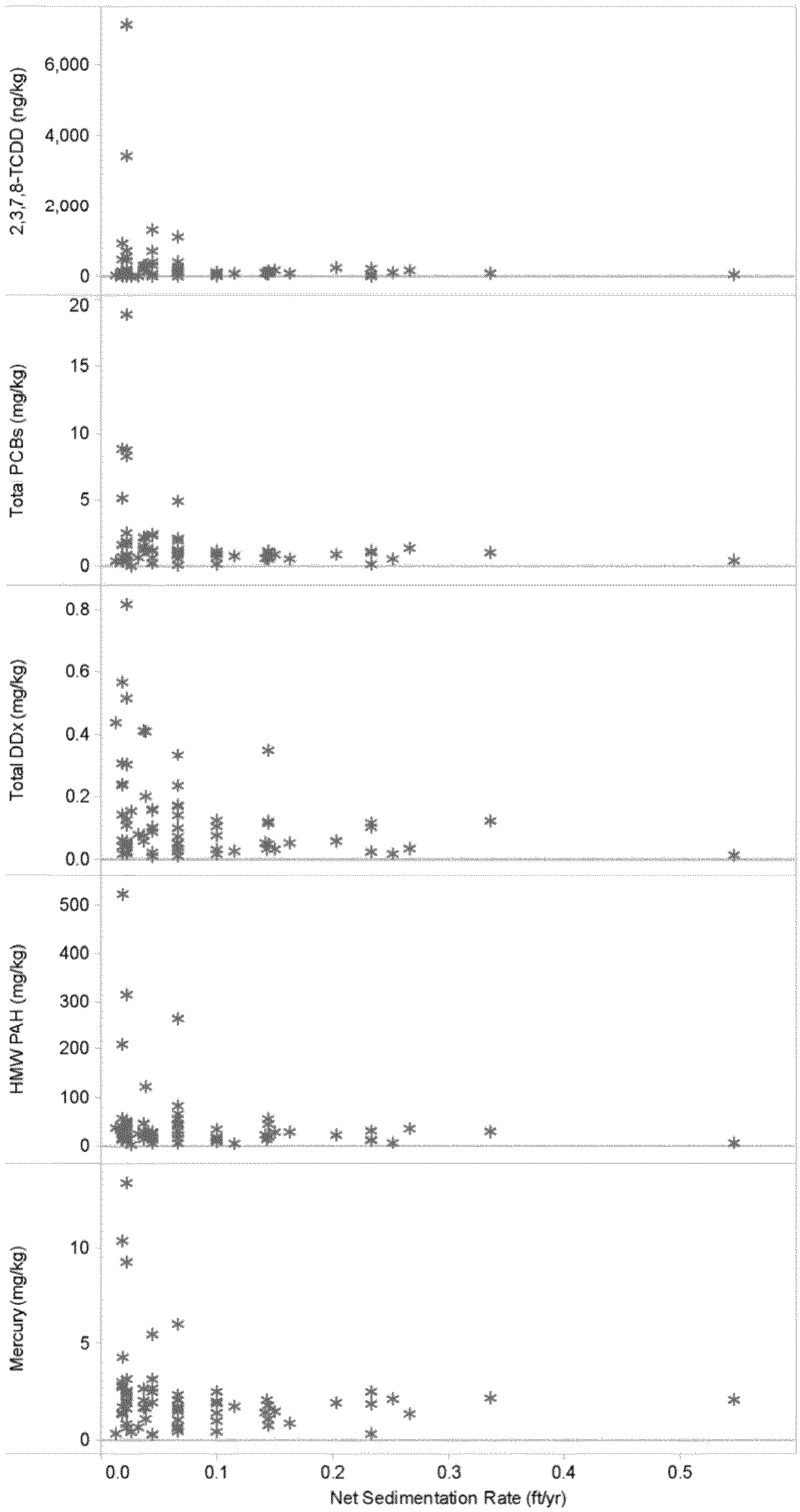
PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-6

LPR Deposition Rates Estimated from 2008 CPG Low-resolution Coring Program Cores

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study



Source: AECOM 2010

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-7

Relationship Between Surface Sediment Concentration and Net Sedimentation Rate in the 2008 LRC Data for Select Contaminants

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 5-8
Cs-137 Classification
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Figure 5-9
Example Cs-137 Profiles above RM 7 (mudflats)
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Notes:
Cesium-137 is represented by the blue line.
Contaminants are represented by the red line.

Figure 5-10
Example Contaminant and Cs-137 Profiles at RM 0, RM 4.5, and RM 7
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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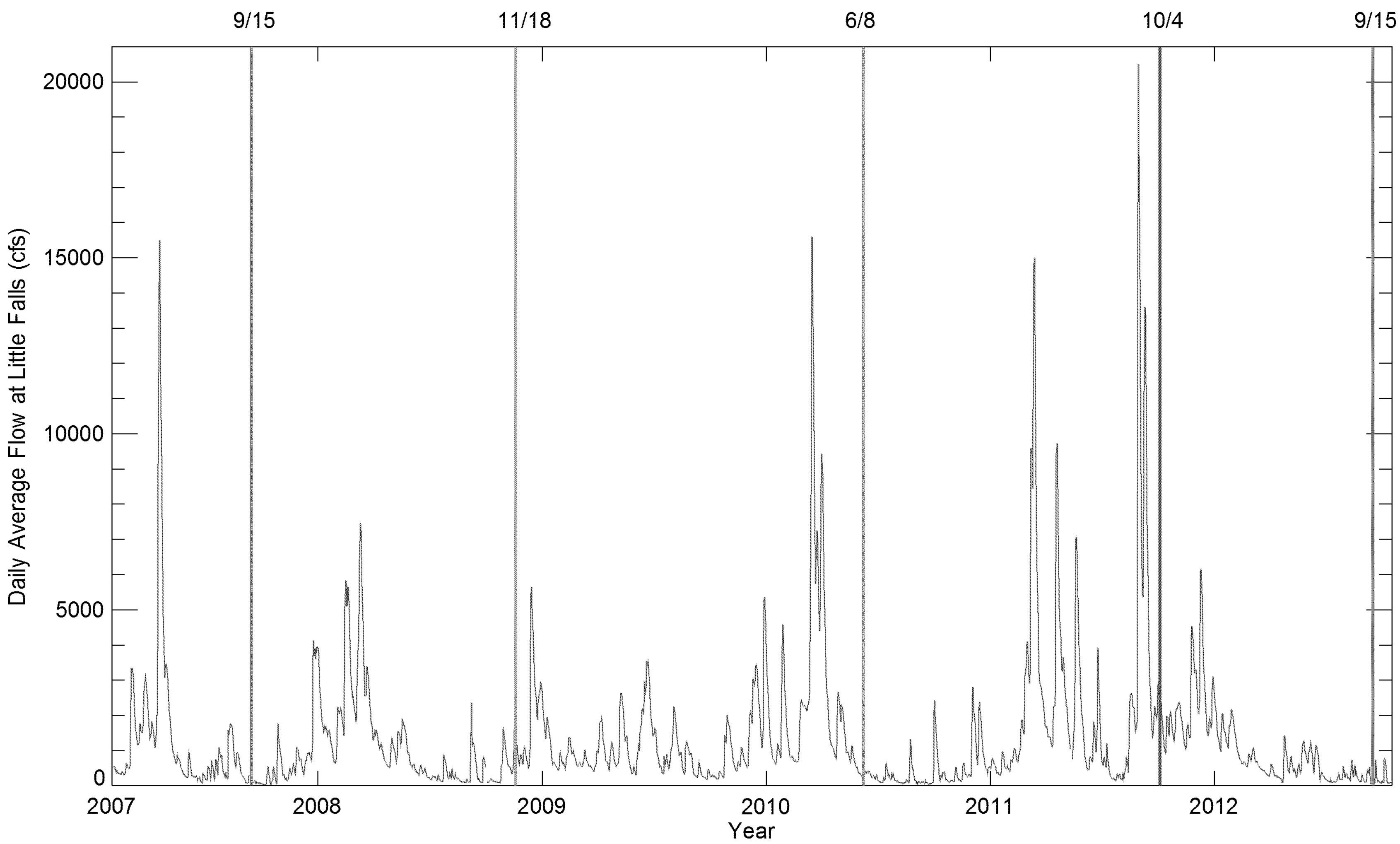
Figure 5-11
Bathymetric Depth Difference
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-12

USGS Flows and Dates of Bathymetric Surveys
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-13a
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-13b
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-13c
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-13d
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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Figure 5-13e
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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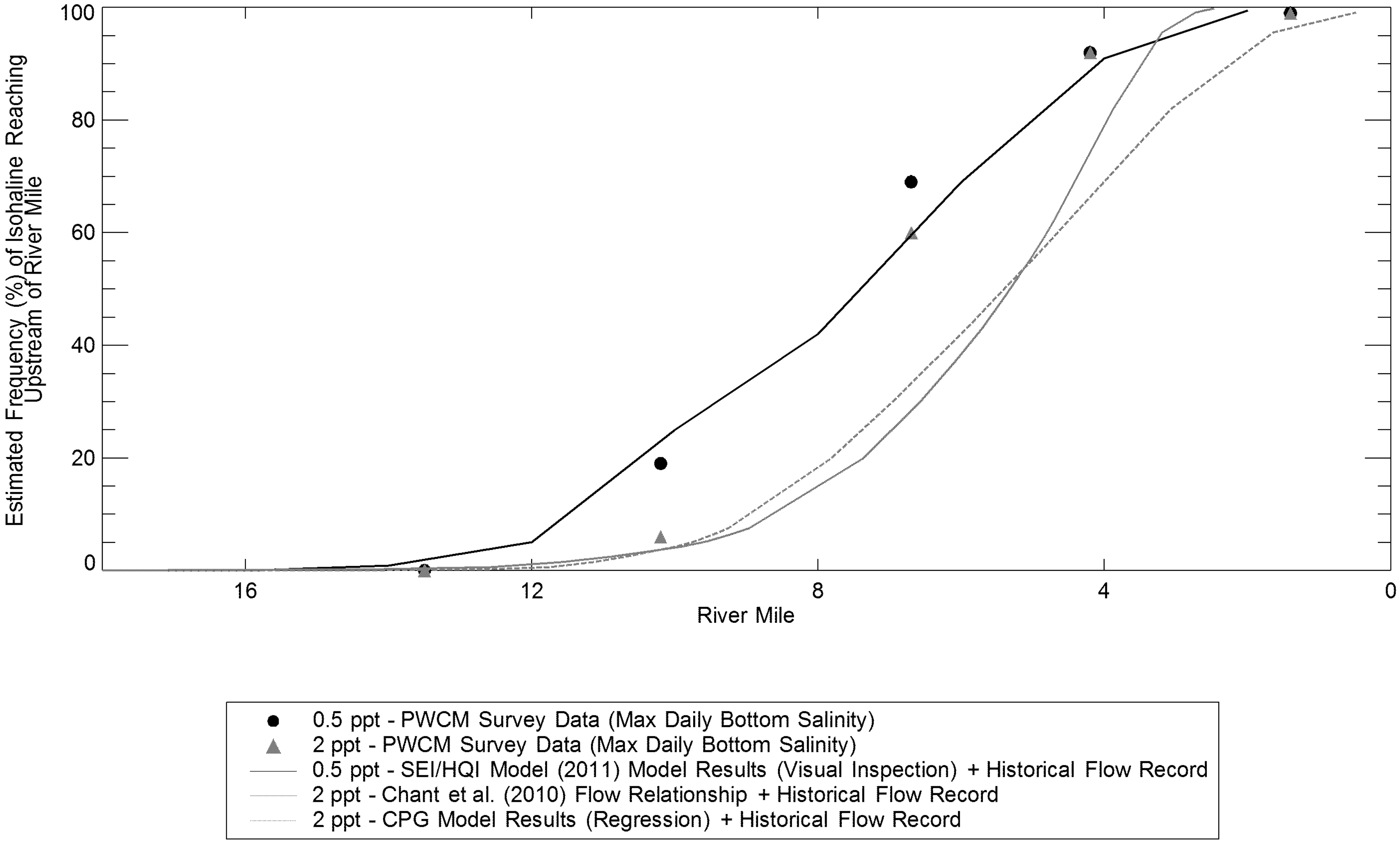
PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-13f
Bathymetry Differentials
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Source: Deltares and Moffatt & Nichol. LPR Bathymetry Analyses based on 2007, 2008, 2010 & 2011 multi-beam surveys. CPG-EPA Collaboration Meeting. June 12, 2012

Figure 5-14
Analysis of the 2007 and 2010 Multibeam Bathymetry Surveys
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-16

Estimates of Salinity Intrusion Frequency on the Lower Passaic River
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

For lines, frequencies are approximate only, estimated using relationships from Chant et al. (2010), CPG model results (regression of values in Figure 5-1), and SEI/HQI 2011 model results (visual inspection of Figure 9 therein) together with the historical flow record at Little Falls. PWCM data points are the observed frequency of maximum daily bottom salinity for the 2009 and 2010 deployments.

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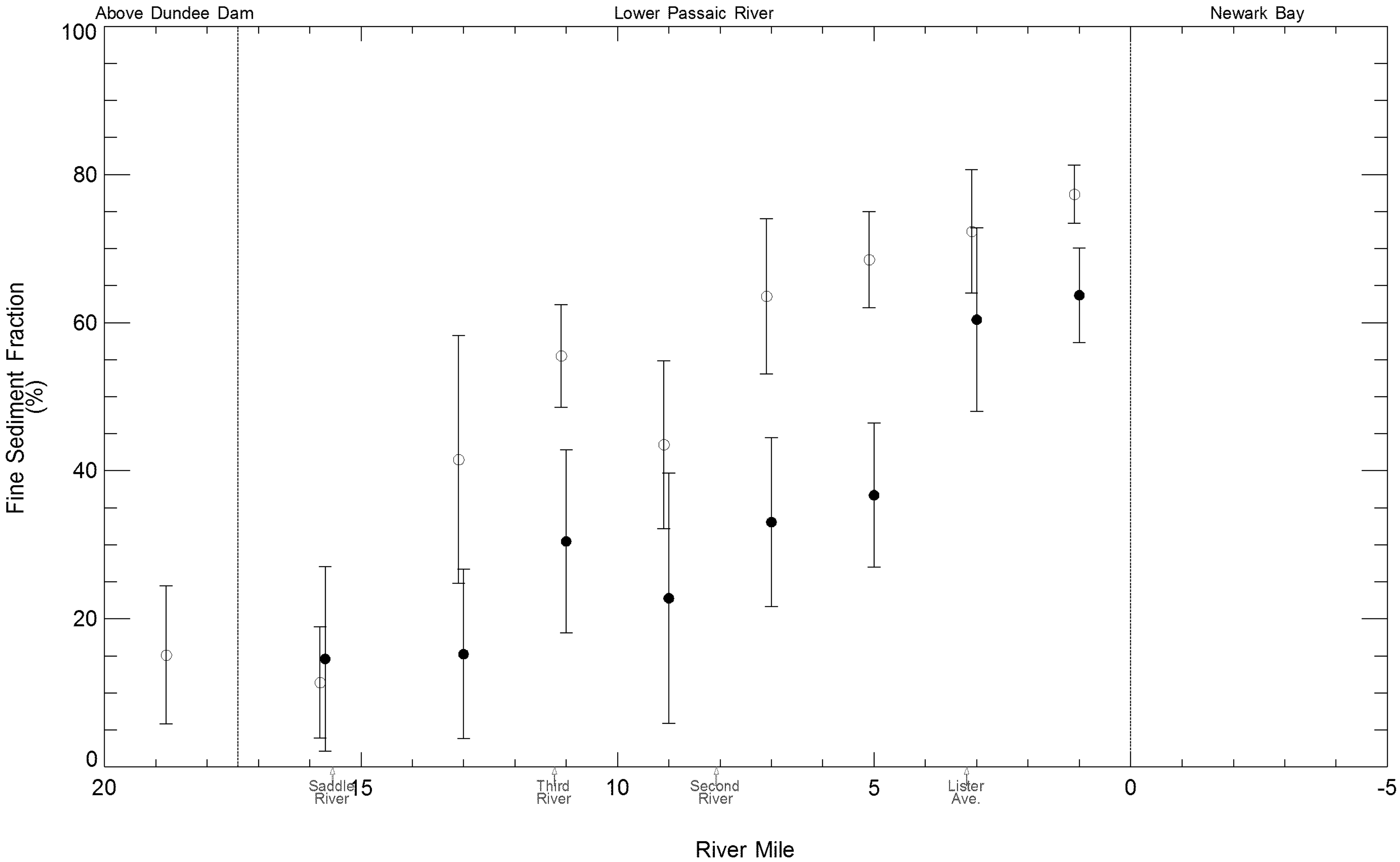

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-17

Percent Fines Concentrations in Surface Sediments of LPR
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). Plot includes all samples with a bottom slice depth of 6 inches or less
Error bars depict limits of +/- 2 standard errors of the mean value within each spatial bin
Newark Bay samples not shown due to data quality issues

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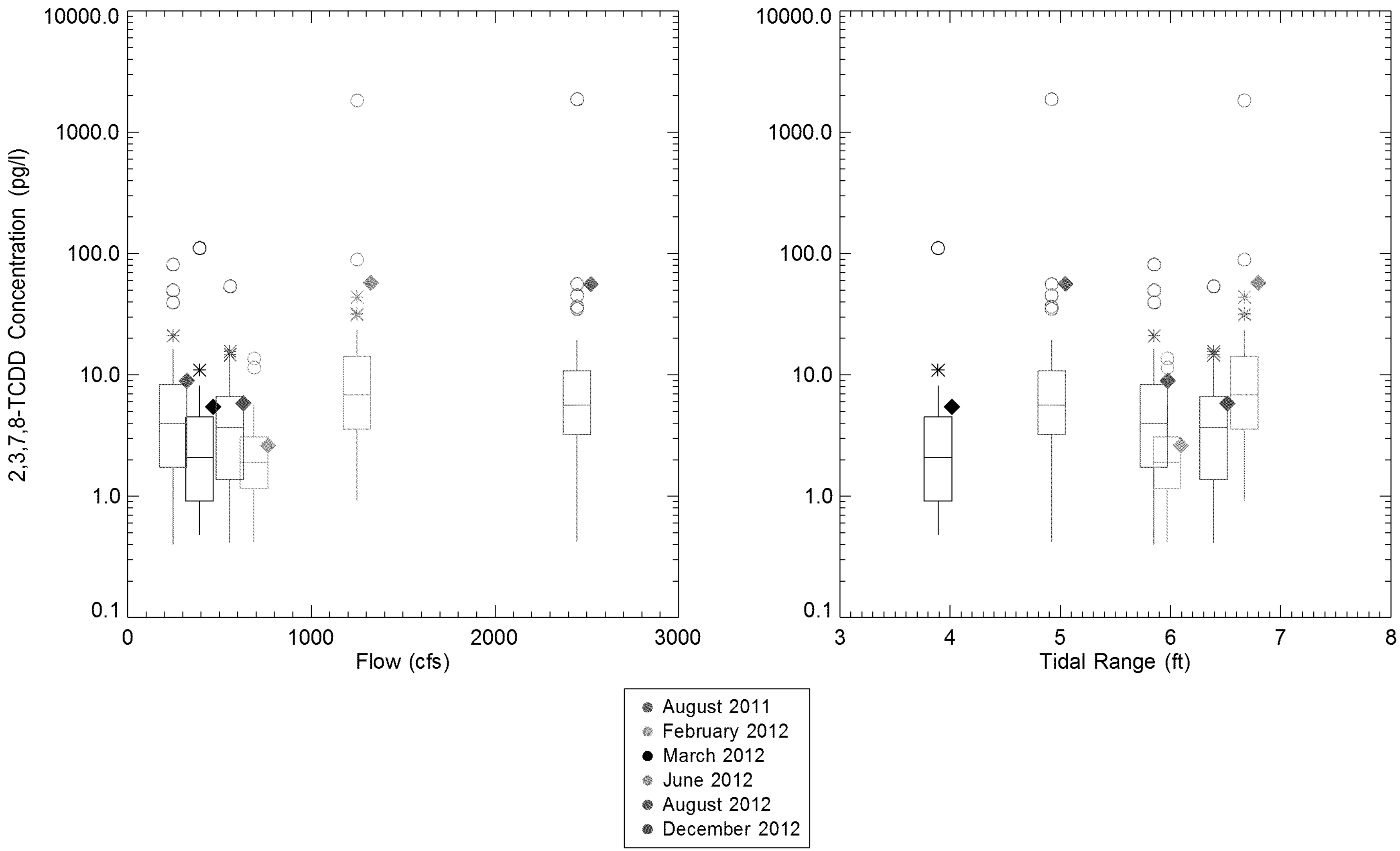

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-18

2,3,7,8-TCDD Concentrations at LPR Stations for Six CWCM Sampling Events
Shown Relative to Left panel: Event-mean Freshwater Flow at Dundee Dam; Right panel: Event-mean Tidal Range at Bergen Point
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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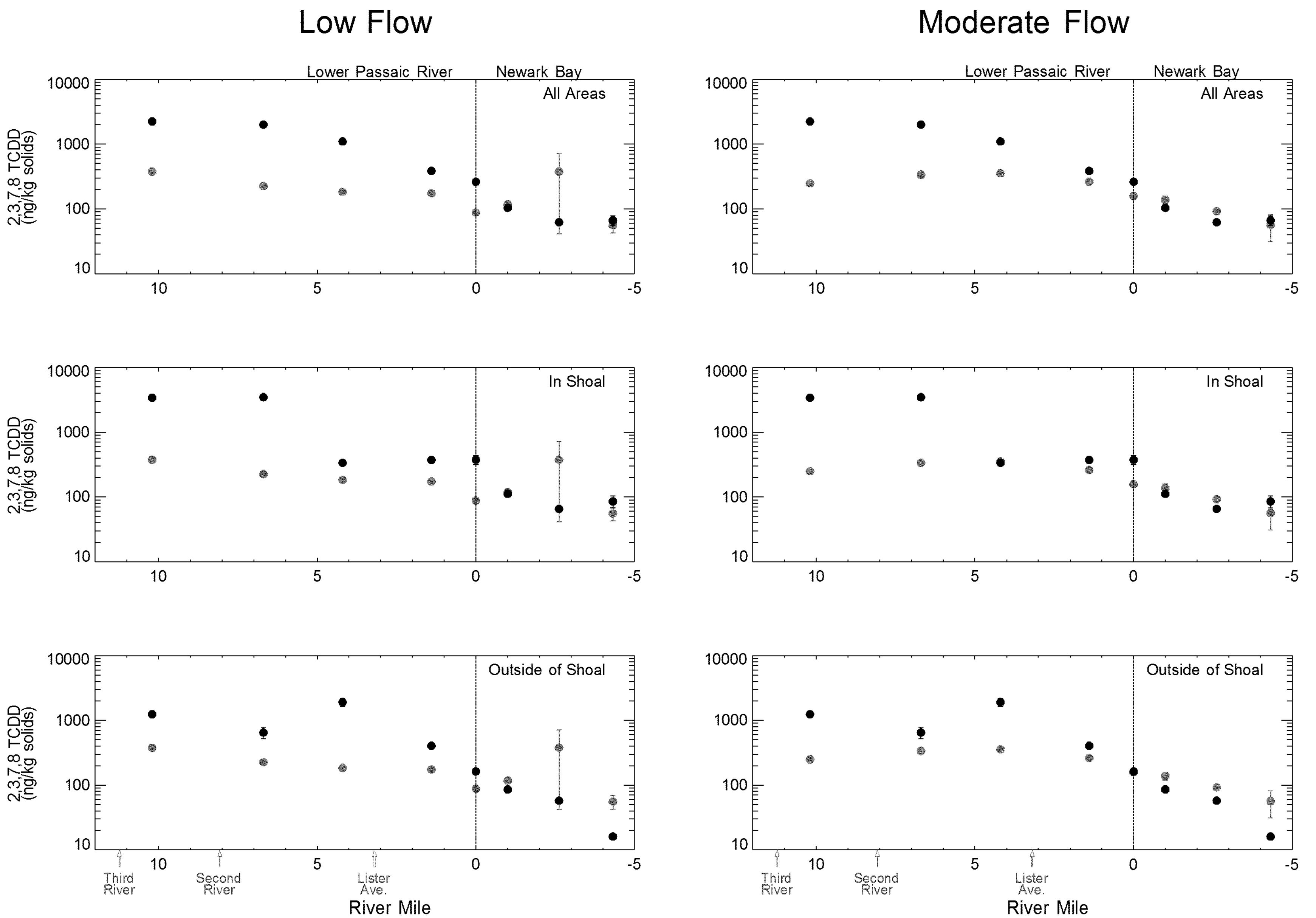

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-19

Spatial Trends of 2,3,7,8 TCDD Concentrations in RM-5-12
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

● Sediment
● Water

Error bars depict limits of +/- 2 standard errors of the mean. Water data is SSC normalized. Sediment data include only post 2000 data (listed in Table 3-1). Data binned spatially by water sampling locations. ND and WC outlier samples have been excluded. Inside and outside of Navigation Channel defined as shoal areas in Newark Bay

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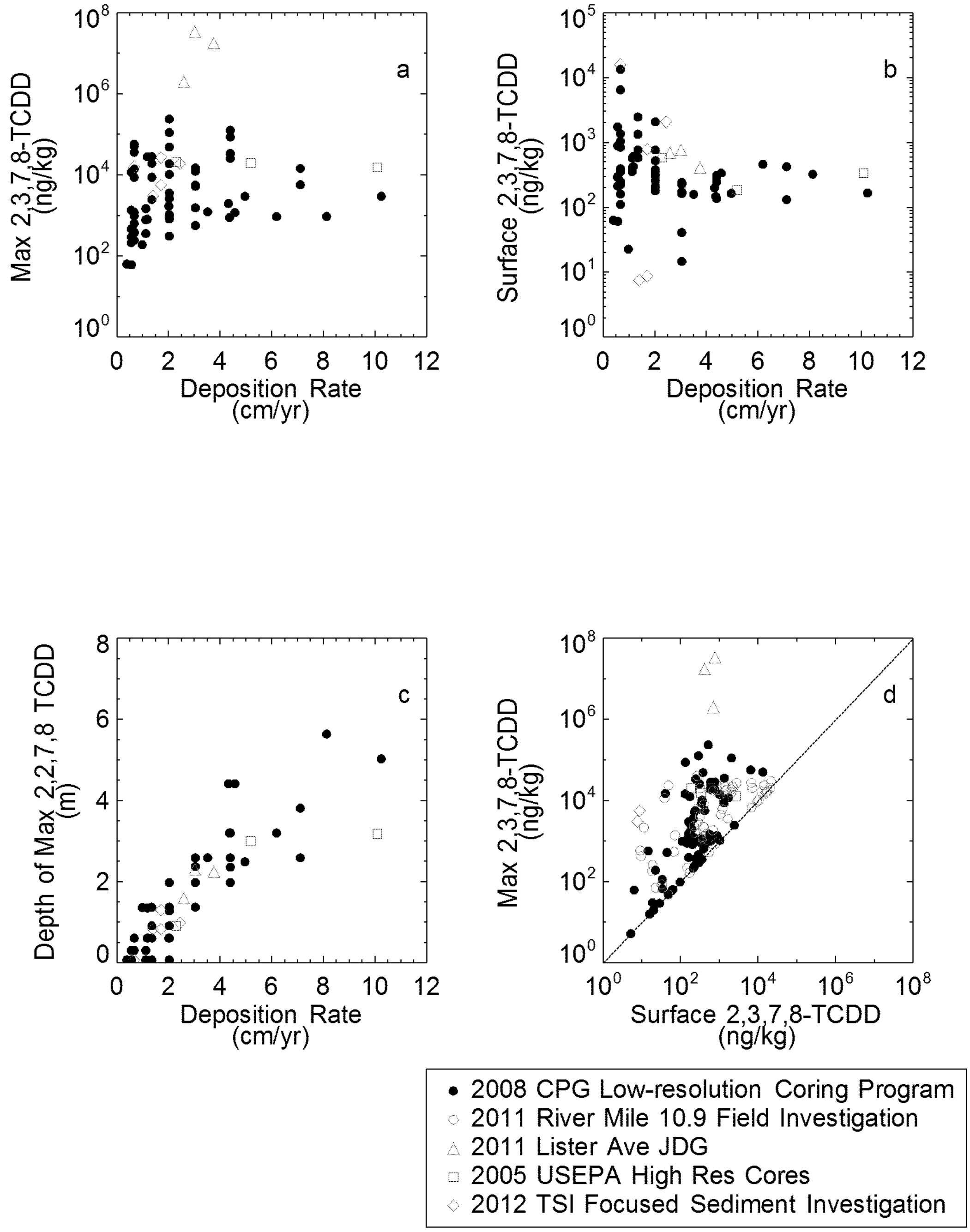


Note: post-2000 data only

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

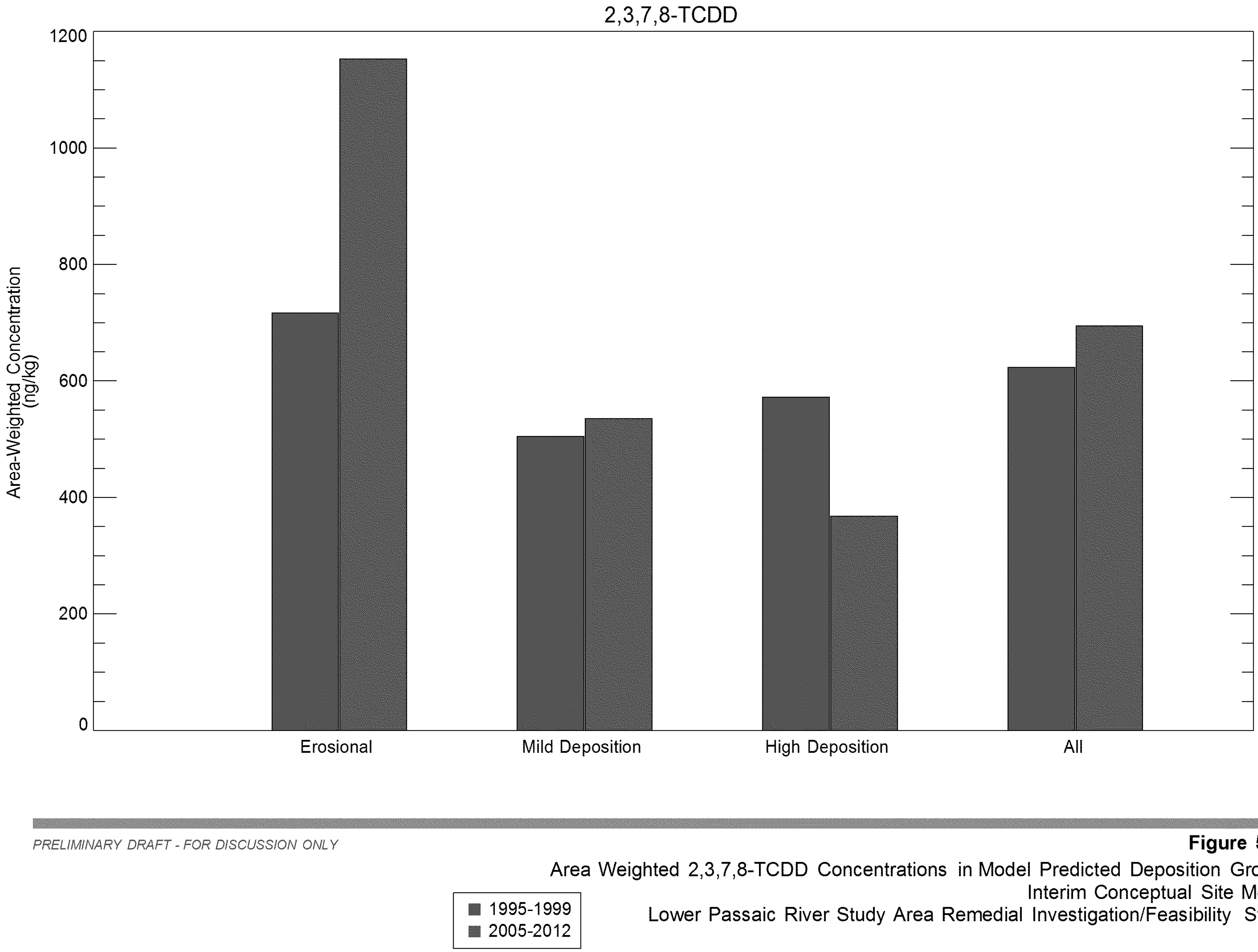
Figure 5-20

2,3,7,8-TCDD Concentrations Between RM 0 and RM 14

a Maximum 2,3,7,8-TCDD Concentration Versus Net Sedimentation Rate; b Surface 2,3,7,8-TCDD Versus Net Sedimentation Rate; c Depth of Maximum 2,3,7,8-TCDD Concentration Versus Net Sedimentation Rate; d Maximum Versus Surface 2,3,7,8-TCDD Concentration

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-21

Area Weighted 2,3,7,8-TCDD Concentrations in Model Predicted Deposition Groups
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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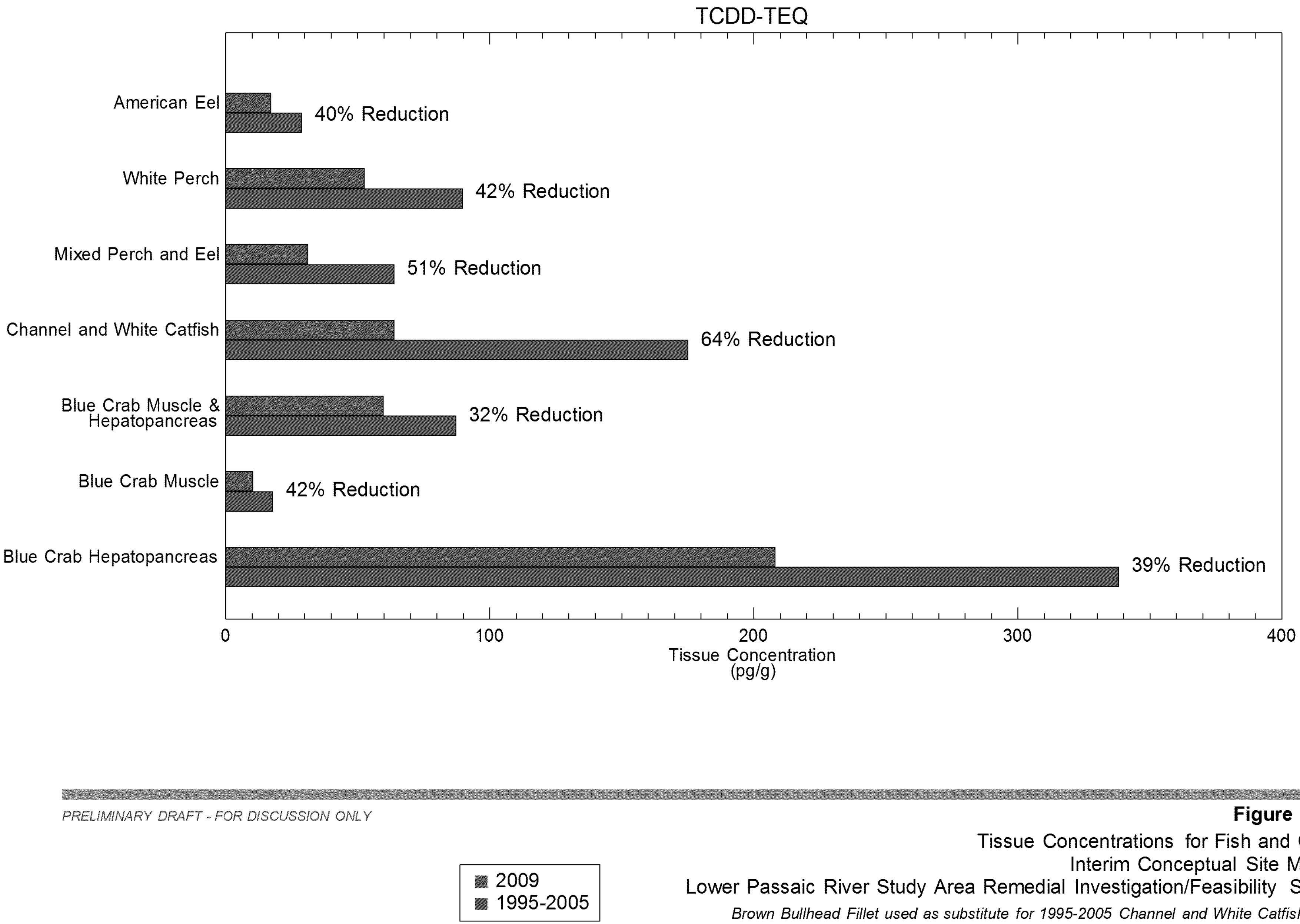

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure 5-22

Tissue Concentrations for Fish and Crab
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Brown Bullhead Fillet used as substitute for 1995-2005 Channel and White Catfish data

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TABLES

Table 2-1

Peak Daily Average Flows at Little Falls

Recurrence interval (years)	2	5	10	25	50	100	200	500
Discharge at Little Falls (cubic feet per second)	7,100	10,500	13,000	16,000	19,000	22,000	25,000	29,000

Table 3-1

Datasets with Post-2000 Sediment Data

2005/2007 TSI Newark Bay Phase I/Phase II
2007 EPA Dundee Lake Core Sampling
2000 TSI Spring RI-ESP Sampling Program
2000 TSI Toxicity Identification Evaluation Study
2005/2006/2008 EPA High-resolution Core Sampling
2007 EPA EMBM
2007-2008 EPA Sediment Sampling Program
2008 CPG Low-resolution Coring Program
2009 CPG RI FSP2 Benthic Sediment Sampling
2009 TSI Phase I Sediment Assessment
2011 CPG River Mile 10.9 Field Investigation
2011 Lister Avenue Site JDG
2012 TSI Focused Sediment Investigation
2012 CPG Supplemental Sampling Program
2005 EPA Core Sediment Sampling for Radionuclide Analysis
2006 EPA Low-Resolution Sediment Coring
2009 TSI Phase I Geotechnical Assessment
Post-2000 Honeywell International Sampling Programs
2004 EPA/USACE Sediment Coring Pilot Project

Table 3-2
CWCM Sampling Event Summary

Sampling Event	Dundee Dam Mean 15-minute Flow (cubic feet per second)	Mean Diurnal Tidal Range (feet)	2,3,7,8-TCDD Data Count LPR Main Stations (non-duplicates)
August 2011	2,448 (range 350 to 3,090)	4.92	40 (3% non-detect)
February 2012	688 (range 529 to 1,160)	5.97	40 (10% non-detect)
March 2012	392 (range 337 to 466)	3.90	40 (35% non-detect)
June 2012	1,249 (range 888 to 1,530)	6.67	40 (0% non-detect)
August 2012	247 (range 165 to 497)	5.85	40 (13% non-detect)
December 2012	557 (range 378 to 736)	6.39	40 (15% non-detect)

Notes:
2,3,7,8-TCDD – 2,3,7,8-tetrachlorodibenzo-p- dioxin
CWCM – chemical water column monitoring
LPR – Lower Passaic River

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Aquatic Plants					
Aquatic plants	X	X	Multiple species are represented, including submerged macrophytes, but are limited because of the physical development of the shorelines and poor light penetration of the water.	Direct contact with surface sediments and surface water from root uptake	Direct contact with groundwater (as porewater)
Invertebrates					
Zooplankton community[1]	X	X	Multiple species are represented; zooplankton are present in the water column.	Ingestion of and direct contact with surface water	
Benthic invertebrate community	X	X	Multiple infaunal species are represented.	Direct contact with the biologically active zone of sediment and surface water and through the ingestion of sediment and surface water	Ingestion of prey and direct contact with groundwater (as porewater)
Macroinvertebrate populations	X	X	Multiple species are represented (crab and crayfish); blue crab and crayfish represent important estuarine and freshwater predators, respectively, and are also preyed on by fish and wildlife.	Direct contact with the biologically active zone of sediment and surface water and through the ingestion of sediment, surface water, and prey	Direct contact with groundwater (as porewater)

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Mollusk populations	X	X	Multiple bivalve species are represented (e.g., oysters and mussels).	Direct contact with the biologically active zone of sediment and surface water and through the ingestion of sediment and surface water	Direct contact with groundwater (as porewater)
Fish					
Benthic omnivore: mummichog	X		Mummichog are an abundant resident fish species; they have a small home range (which represents localized exposure).	Direct contact with and incidental ingestion of surface sediments; ingestion of prey; ingestion of and direct contact with surface water	Direct contact with groundwater (as porewater)
Benthic omnivore: banded killifish/ darter		X	Benthic feeders are in direct contact with sediments while feeding (high potential for exposure to sediment- associated chemicals); selected receptors have a long life span.	Direct contact with and incidental ingestion of surface sediments; ingestion of prey; ingestion of and direct contact with surface water	Direct contact with groundwater (as porewater)

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Invertivore: white perch	X		Younger perch (up to approximately 2 years of age) were selected over other invertivorous species (e.g., winter flounder and Atlantic tomcod) because white perch have been observed in the LPRSA and have strong site fidelity and small home range (representing localized exposure); selected receptor has a long life span.	Ingestion of prey; ingestion of and direct contact with surface water	Direct contact with and incidental ingestion of surface sediments
Invertivore (pelagic): channel catfish/bullhead		X	Selected receptors are small freshwater residents; they have a limited home range.	Direct contact with and incidental ingestion of surface sediments; ingestion of prey; ingestion of and direct contact with surface water	

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Carnivore/piscivore (migratory): American eel	X		American eel were selected over other migratory piscivores (e.g., striped bass) because of their unique life history (catadromous species spawn in the Atlantic Ocean, migrate to freshwater as larvae, and remain for 5 to 20 years until they are sexually mature). There is some uncertainty associated with the wide home range of American eels and the potential for their exposure to chemicals outside the LPRSA.	Ingestion of prey; ingestion of and direct contact with surface water	Direct contact with and incidental ingestion of surface sediments
Piscivore: largemouth bass		X	Largemouth bass prey primarily on fish (high potential for exposure to bioaccumulative chemicals) and have a long life span; largemouth bass have been observed in the LPRSA.	Ingestion of prey; ingestion of and direct contact with surface water	Direct contact with and incidental ingestion of surface sediments

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Amphibians/Reptiles					
Amphibians and reptiles	X	X	Multiple species may be represented (e.g., bullfrog, snapping turtle) in the freshwater portion of the LPRSA; there is a very limited presence of amphibians and reptiles in the estuarine portion of the LPRSA.	Direct contact with surface water; ingestion of prey	Direct contact with and incidental ingestion of surface sediments; ingestion of surface water; direct contact with groundwater (as porewater)
Birds[2]					
Aquatic herbivore (dabbling duck): mallard duck	X	X	Mallards have been observed year round in the lower portion of the LPRSA.[3]	Ingestion of biota prey; ingestion of surface water; incidental ingestion of surface sediment	Direct contact with surface water and surface sediment
Sediment probing invertivore: spotted sandpiper	X	X	These shorebirds are frequently observed in the lower portion of the LPRSA. They have a limited foraging range during breeding season and feed by probing in mudflat sediments (high potential for exposure to contaminated sediments in intertidal habitats).	Ingestion of biota prey; incidental ingestion of surface water and surface sediment	Direct contact with surface water and surface sediment

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Migratory piscivore: heron/egret species	X	X	Numerous studies on the life history and sensitivity to bioaccumulative chemicals are available; herons and egrets feed almost exclusively on fish (high exposure to bioaccumulative chemicals); some species have a relatively small home range from their nesting sites during breeding season.	Ingestion of biota prey; incidental ingestion of surface water and surface sediment	Direct contact with surface water and surface sediment
Resident piscivore: belted kingfisher	X	X	Belted kingfisher are year-round residents in the LPRSA; their diet is almost exclusively fish. Kingfisher use the LPRSA for breeding. They were selected over herring gull because herring gull are scavengers with a highly variable diet.	Ingestion of biota prey; incidental ingestion of surface water and surface sediment	Direct contact with surface water and surface sediment

Table 4-1

Selected Potential Ecological Receptors of Concern

Receptor	Estuarine Receptor	Freshwater Receptor	Rationale	Potentially Complete and Major Exposure Pathway	Potentially Complete and Minor Exposure Pathway
Mammal[4]					
Piscivore : river otter	X	X	River otter are semi-piscivorous. Their foraging range can be limited to length of LPRSA; however, potential LPRSA habitat is very limited, and otters have not been observed in LPRSA; uncertainty regarding site use of the river otter in the LPRSA is assumed to be very high.[5]	Ingestion of biota prey; incidental ingestion of surface water and surface sediment	Direct contact with surface water and surface sediment

Notes:

LPRSA – Lower Passaic River Study Area

1 – Zooplankton exposure to chemical concentrations in the water column (i.e., surface water) will be evaluated using the same analysis as that conducted for the benthic invertebrate community assessment.

2 – No raptor bird species was selected. The diet of raptors is not expected to be limited to the LPRSA or LPRSA contaminants.

3 – The mallard duck is not proposed to be a quantitatively evaluated receptor because the potential exposure to chemicals is expected to be higher for other higher trophic level avian receptors (i.e., invertivores and piscivores).

4 – The selected piscivorous mammal (i.e., river otter) is expected to be protective of herbivorous mammals (e.g., muskrat) and omnivorous mammals (e.g., raccoon); therefore, no receptors were selected for those feeding guilds. The potential exposure to chemicals is expected to be higher for piscivorous mammals. Furthermore, the omnivorous diet of the scavenging raccoon (which includes residential garbage) is not expected to be limited to the LPRSA or LPRSA contaminants, whereas the diet of piscivorous mammals may be more limited to the LPRSA.

5 – Selection of the river otter may be overly conservative for the protection of mammals that currently use habitat along the LPRSA.

Table 4-2

Shoreland Land Use Along the Lower Passaic River

Land Use	RM 0 to 7 (percent)	RM 7 to 17.4 (percent)
Agriculture	0	0.6
Industrial/commercial/urban	72.6	32.4
Infrastructure	16.4	22.4
Recreational/open space	10.6	33.8
Residential	0.4	10.2
Wetlands	0	0.6

APPENDIX A
EVALUATION OF THE LOW RESOLUTION CORING DATA

The Low Resolution Coring (LRC) program comprises sediment samples collected in 2008 to characterize the nature and extent of contaminants in the Lower Passaic River Study Area (LPRSA; ENSR 2008; see AECOM [2011] for more details on the program and associated contaminant data). The sedimentation rates estimated from this dataset are described in this appendix.

A.1 RADIOCHEMISTRY ANALYSIS

Sedimentation rates were evaluated from Radium-226 (Ra-226), Cesium-137 (Cs-137), and Lead-210 (Pb-210; measured as Polonium-210 [Po-210]) data. The notable features of a Cs-137 profile include the onset of Cs-137 in sediments (corresponding to approximately the 1954 sediment horizon, when Cs-137 was first introduced through atmospheric testing of atomic weapons), the peak Cs-137 concentration (corresponding to approximately the 1963 sediment horizon, when the maximum fallout from atomic weapons testing occurred), and the pattern of Cs-137 between the peak concentration and the lower concentrations of more recently deposited surficial sediments. The Cs-137 profiles were reviewed and classified as A, B, C, or D based on the presence of these dating markers (see Table A-1 and discussion below; see Table A-2 for individual core classifications). Core profiles classified as A or B are considered to represent a stable sediment bed. The converse is not necessarily true—a core without an intact Cs-137 profile may or may not indicate a stable sediment bed. Other lines of evidence need to be considered to evaluate sedimentation when Cs-137 profiles are not datable. Cores with no markers were classified as D, and could not be dated with the Cs-137 data. Either Cs-137 was not detected or detected at low levels, or the profile did not exhibit identifiable dating markers.

Based on evaluation of cores where no sedimentation was evident, background Cs-137 concentration in the region was estimated as 0.05 picocuries per gram (e.g., 2008-CLRC-100, -105, and -107). Locations where Cs-137 concentrations were non-detect or on the order of background were assigned a D classification.

Some Cs-137 profiles prevented a straightforward classification. For example, in many of the profiles, the concentration decline from peak to surface was not monotonic (e.g., 2008-CLRC-027 and 2008-CLRC-033). The reasons for such patterns include measurement uncertainty, variations in sediment properties (e.g., total organic carbon or grain size), or an active mixing zone at the sediment surface. At other locations, a secondary Cs-137 peak located below the primary peak concentration was observed (e.g., 2008-CLRC-024), which could be indicative of the 1959 horizon (a year when significant atmospheric atomic weapons testing was performed). For such locations, nearby sedimentation rates and geomorphic location of the core were considered to support the classification of the Cs-137 profile.

Table A-2 presents the sedimentation rates calculated from the Cs-137 profiles. To calculate the rates, the mid-depth of the segments that contained the onset of Cs-137 and the maximum Cs-137 were identified for each core in which these features were present. Sedimentation rates were calculated as the difference between the two segment depths divided by the number of years (e.g., 45 years between 1963 and 2008). Cores where all three net sedimentation rates (1963 to 2008, 1954 to 2008, and 1954 to 1963) could be calculated were assigned an A classification. Cores where only one net sedimentation rate could be calculated were assigned a B or C classification (1963 to 2008 for B classification; 1954 to 2008 for C classification). Most cores were classified as A or D.

Pb-210 in sediment results from ongoing atmospheric fallout (referred to as unsupported lead concentration), which, after deposition onto the sediment bed, mixes with sediments that contain Pb-210 from the decay of naturally occurring uranium (background or supported Pb-210 concentration) within the sediments. The former is a measure of continuous sediment deposition, and can be distinguished from the latter by using the Ra-226 concentration (assuming that Ra-226 and Pb-210 are in secular equilibrium).

Separation of the supported and unsupported Pb-210 fractions was achieved by subtracting the Ra-226 levels from the Po-210 measurements (Appleby 2000; Holmes 1998). The unsupported Pb-210 levels were then plotted on a logarithmic scale as a function of depth within the sediment core and visually examined for the expected pattern (i.e., levels that are typically higher at the surface, and a decline with depth to a relatively constant background condition; the analysis excluded outliers). The slope of the regression line was used to calculate the net sedimentation rate (where the constant is a function of the Pb-210 decay rate; Jeter 2000). A break or change in the slope of the Pb-210 data, which can suggest a temporal change in sedimentation patterns, was observed at two locations. At these locations (2008-CLRC-010 and 2008-CLRC-017) two sedimentation rates were calculated, the upper one characterizing more recent sedimentation rates and the deeper one characterizing historical sedimentation rates. Note, however, that the segmentation of the LRC cores (i.e., low resolution segments of 0.5 to 2 feet) may be too coarse to support a fine-scale evaluation of radiochemistry data and sedimentation patterns, and may be the reason slope breaks were not readily apparent in the LRC data. Net sedimentation rates from the Pb-210 data are included in Table A-2, along with the correlation coefficient of the line fit to the unsupported Pb-210 data. Plots for each core are included on Figures A-1a through A-1l.

In general, sedimentation rates calculated from the Cs-137 and the Pb-210 data were consistent. However, the rates are not necessarily expected to be the same for both methods because they may represent different time intervals (i.e., the Cs-137 dating yields long-term average net sedimentation rates, whereas Pb-210 analyses provide more contemporary sedimentation rate estimates). For example, sedimentation rates may have changed over time due to historical dredging activities and cessation of dredging in the mid-1900s, which may be captured differently in the two methods. The consistency of the rates between the two methods with river location and generally as a function of dredging history indicate that the LRC radiochemistry data provide a reliable means to evaluate net sedimentation.

A.2 REFERENCES

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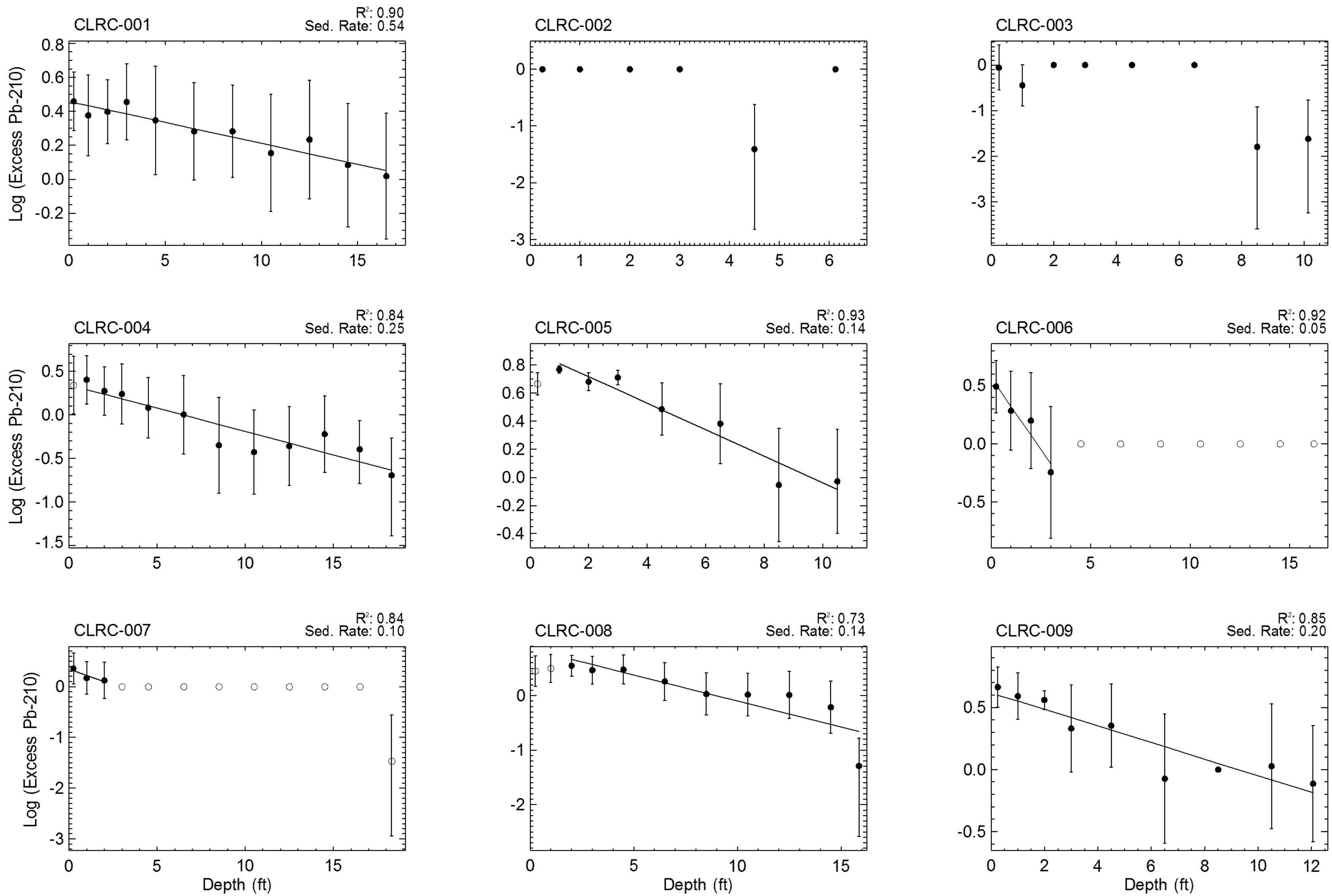
Jeter, H.W., 2000. Determining the ages of recent sediments using measurements of trace radioactivity. Terra et Aqua 78:21-28.

APPENDIX A
FIGURES



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1a

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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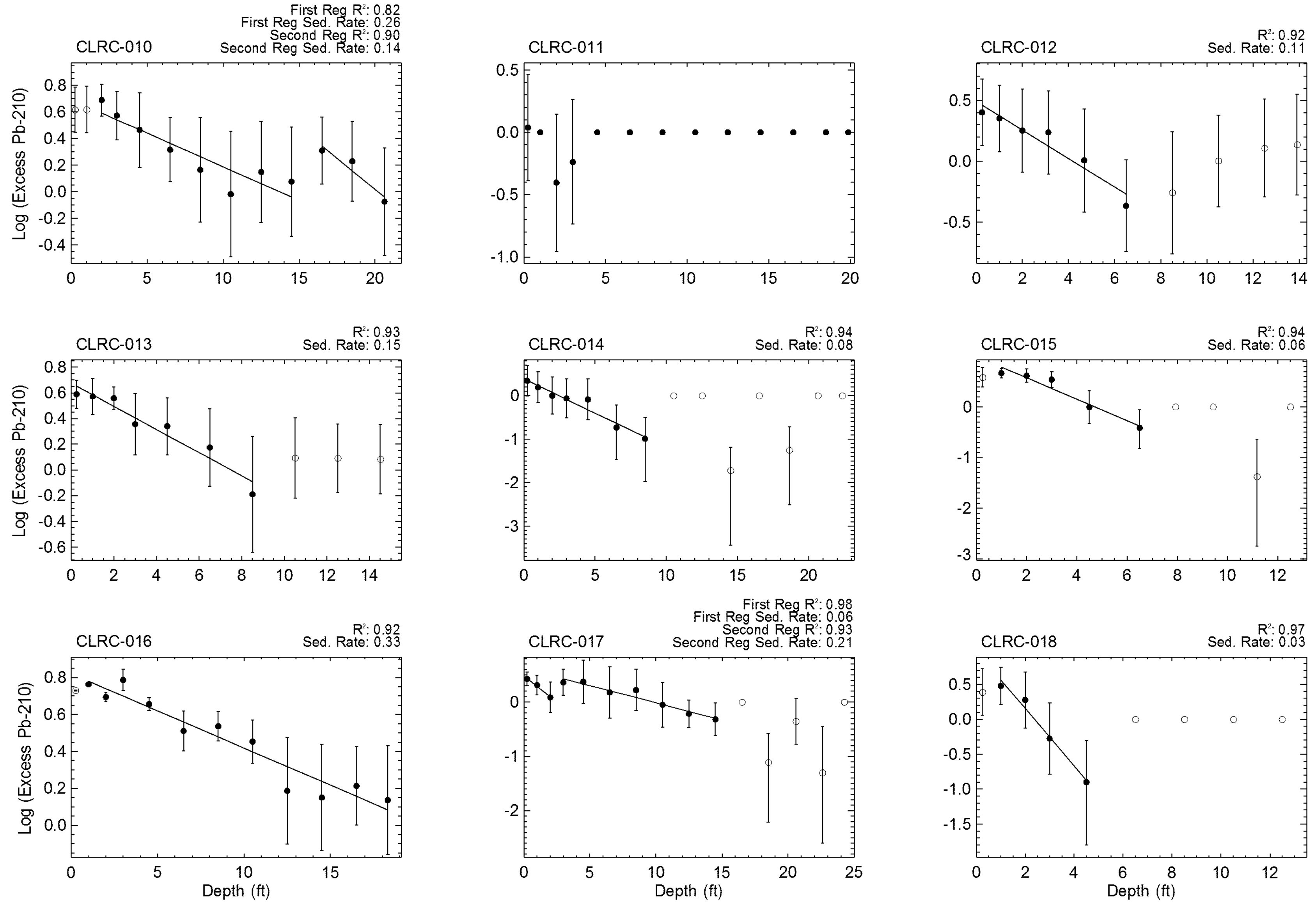

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1b

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
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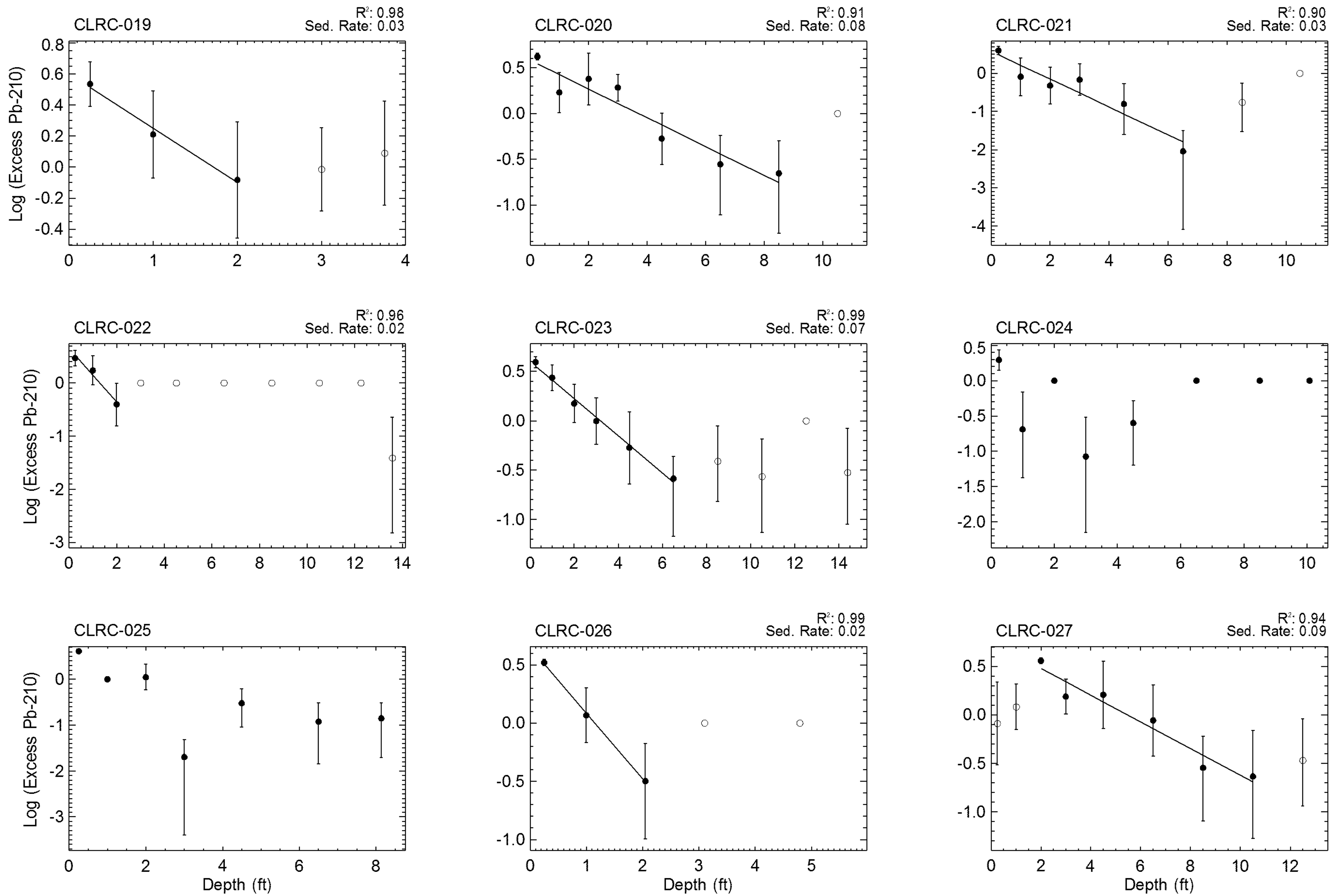

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1c

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
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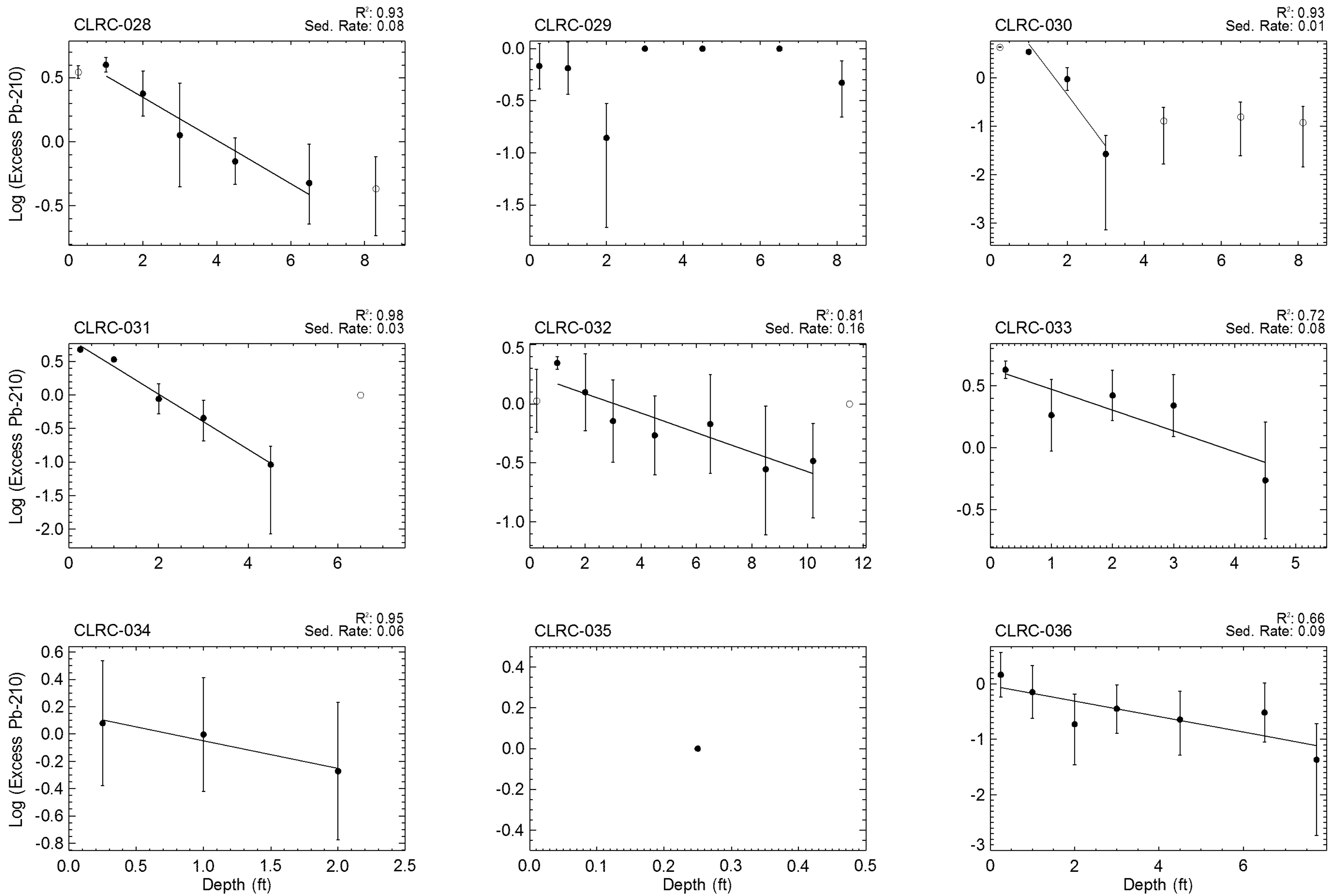

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1d

Pb-210 Depth Profile in 2008 LRC Data
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Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
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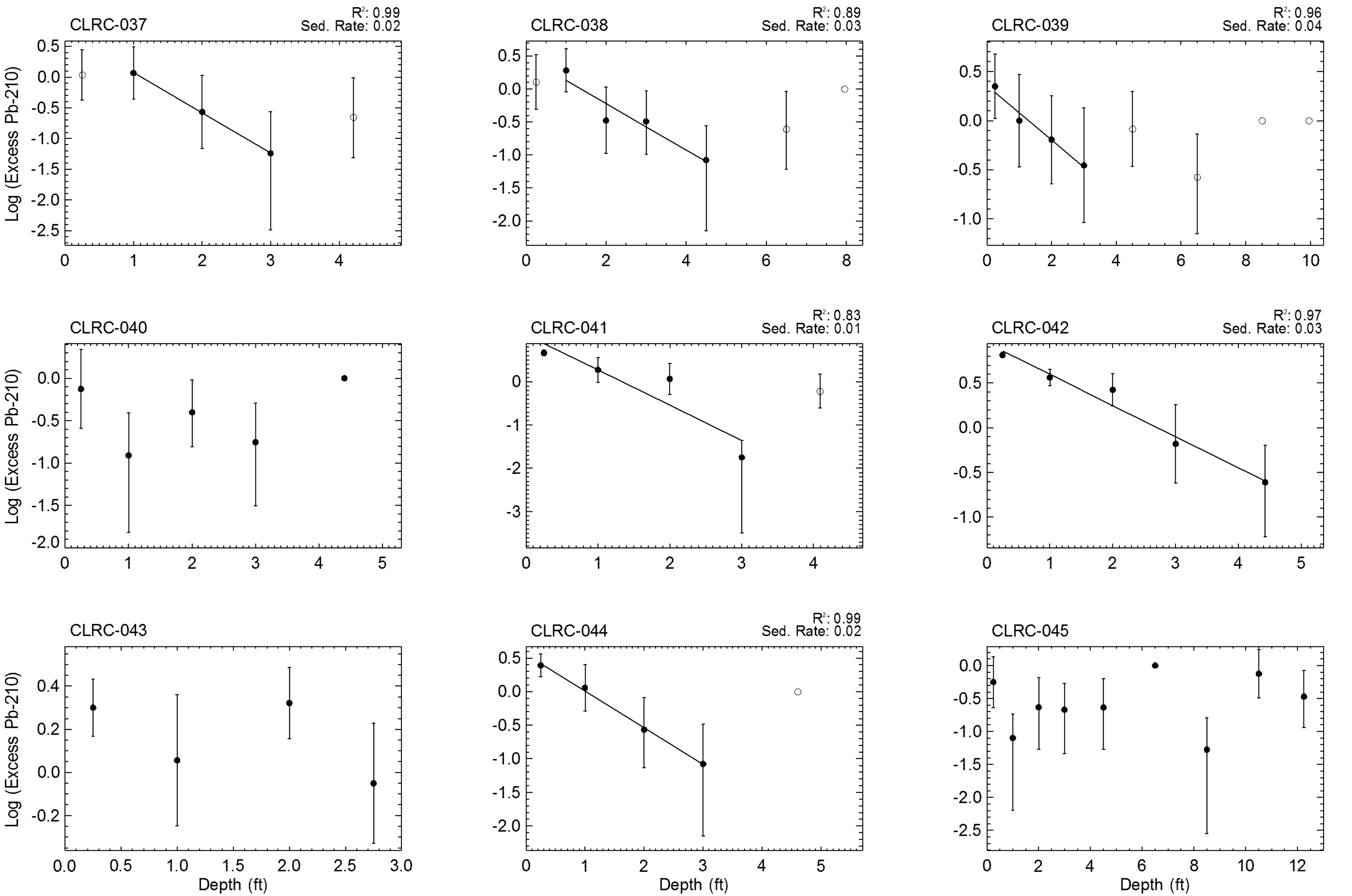

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1e

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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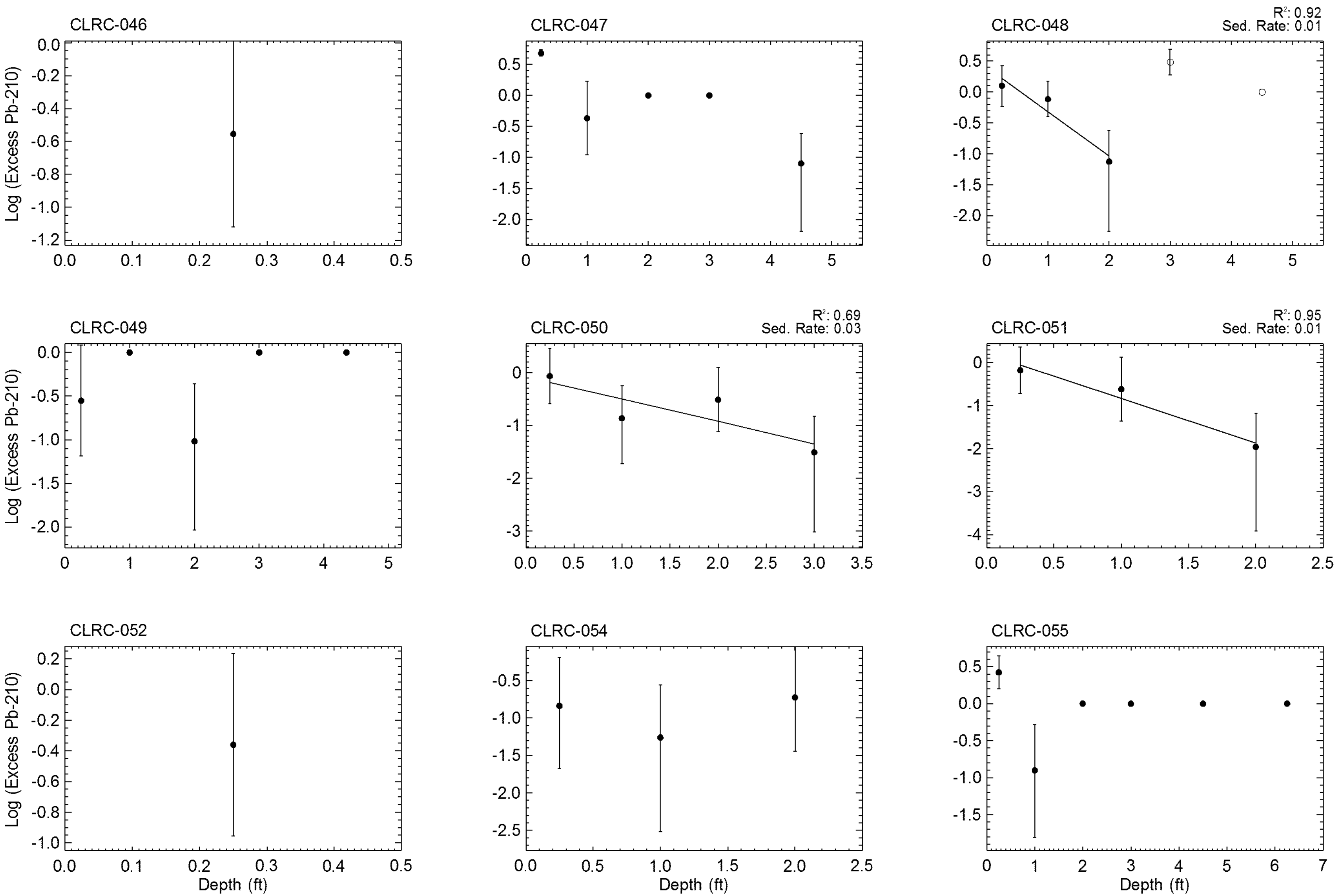

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1f

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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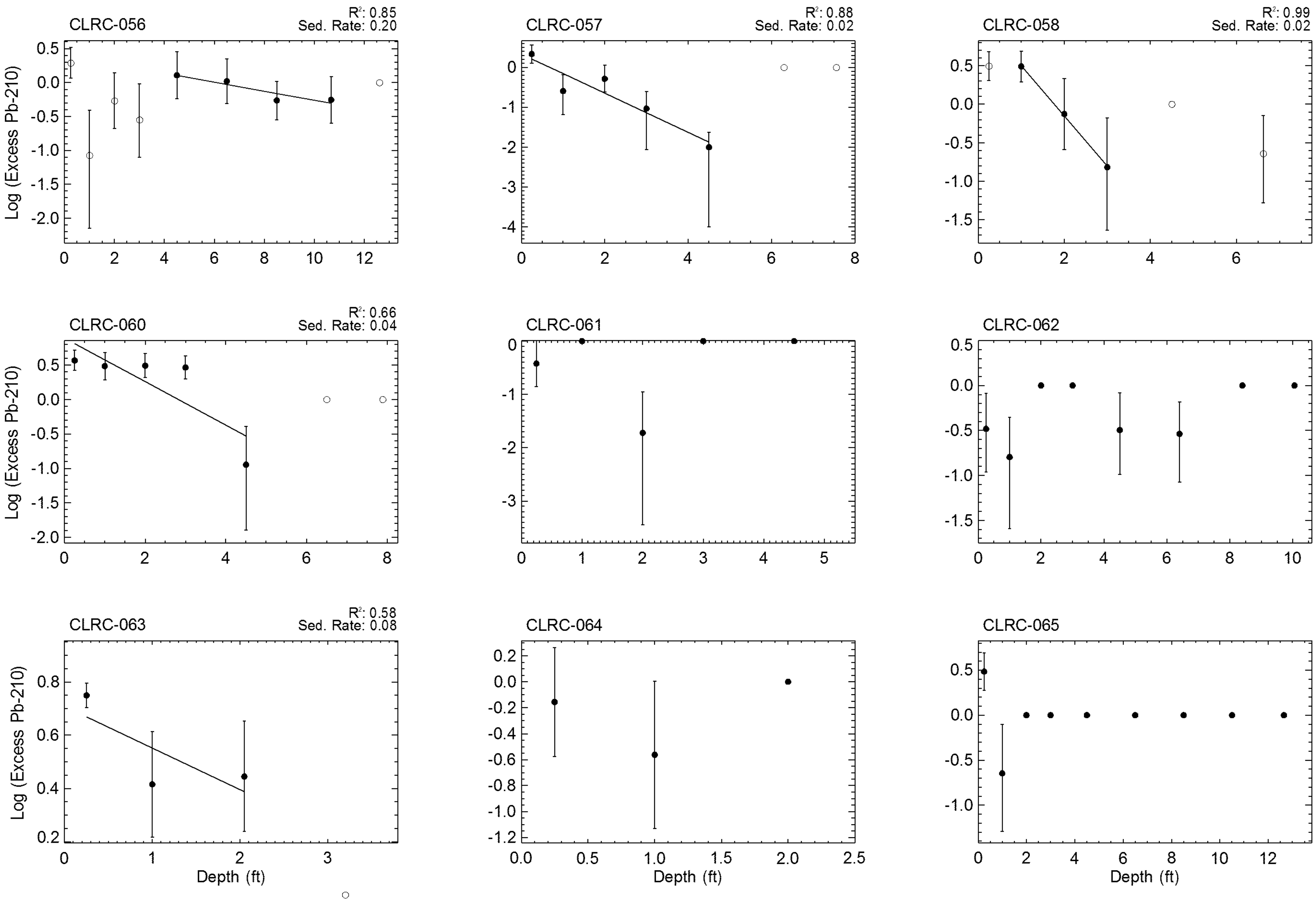

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1g

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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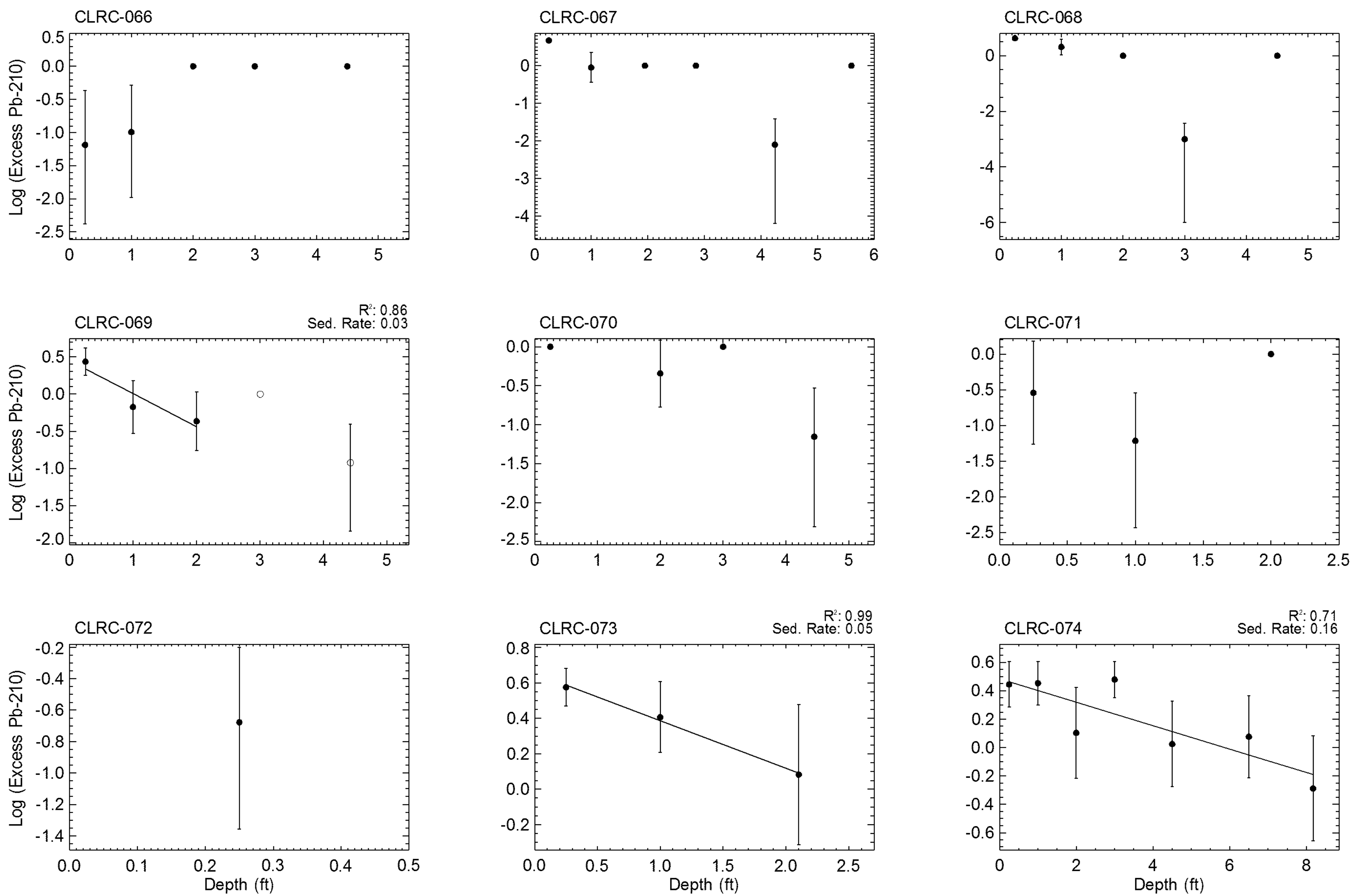

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1h

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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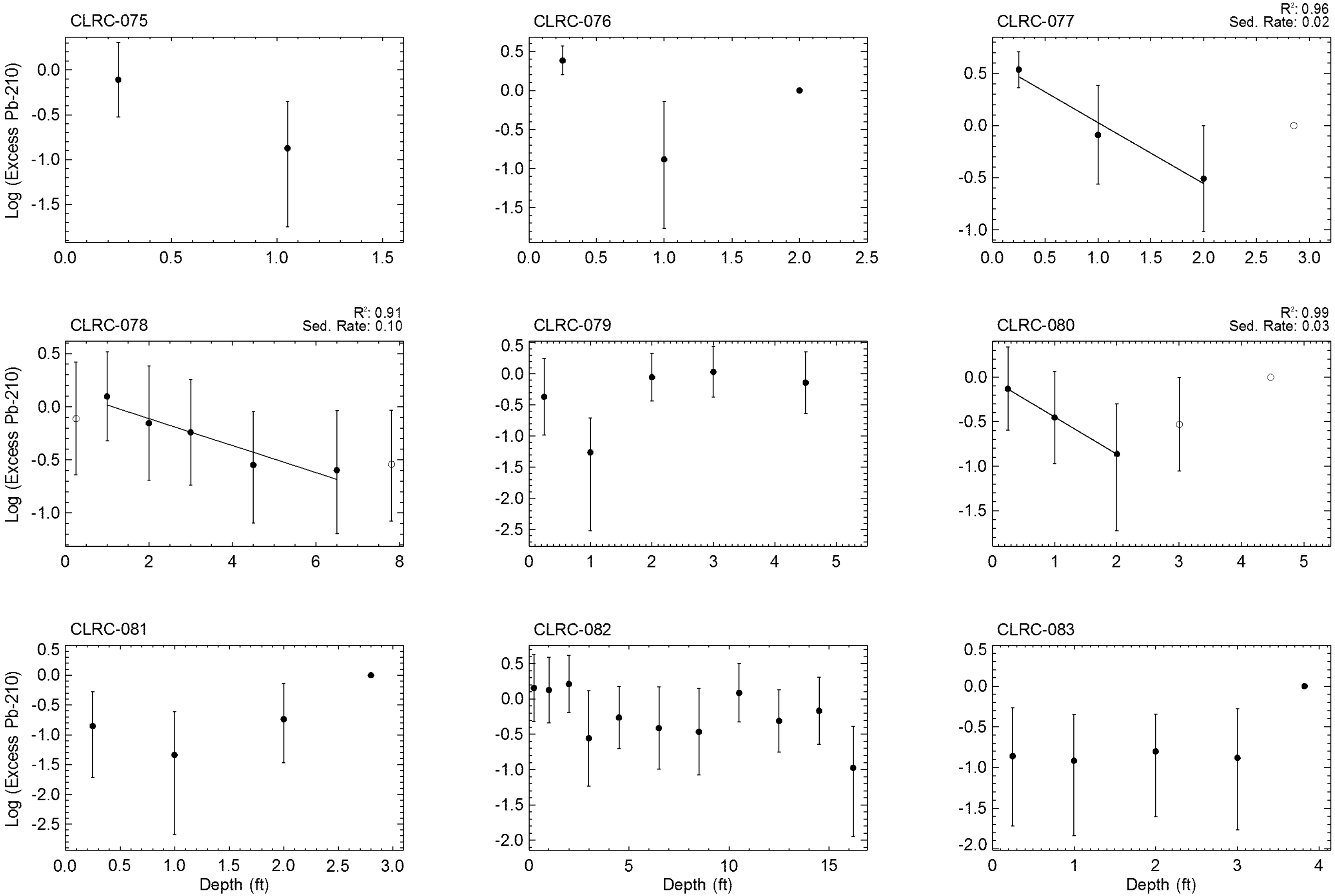

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1i

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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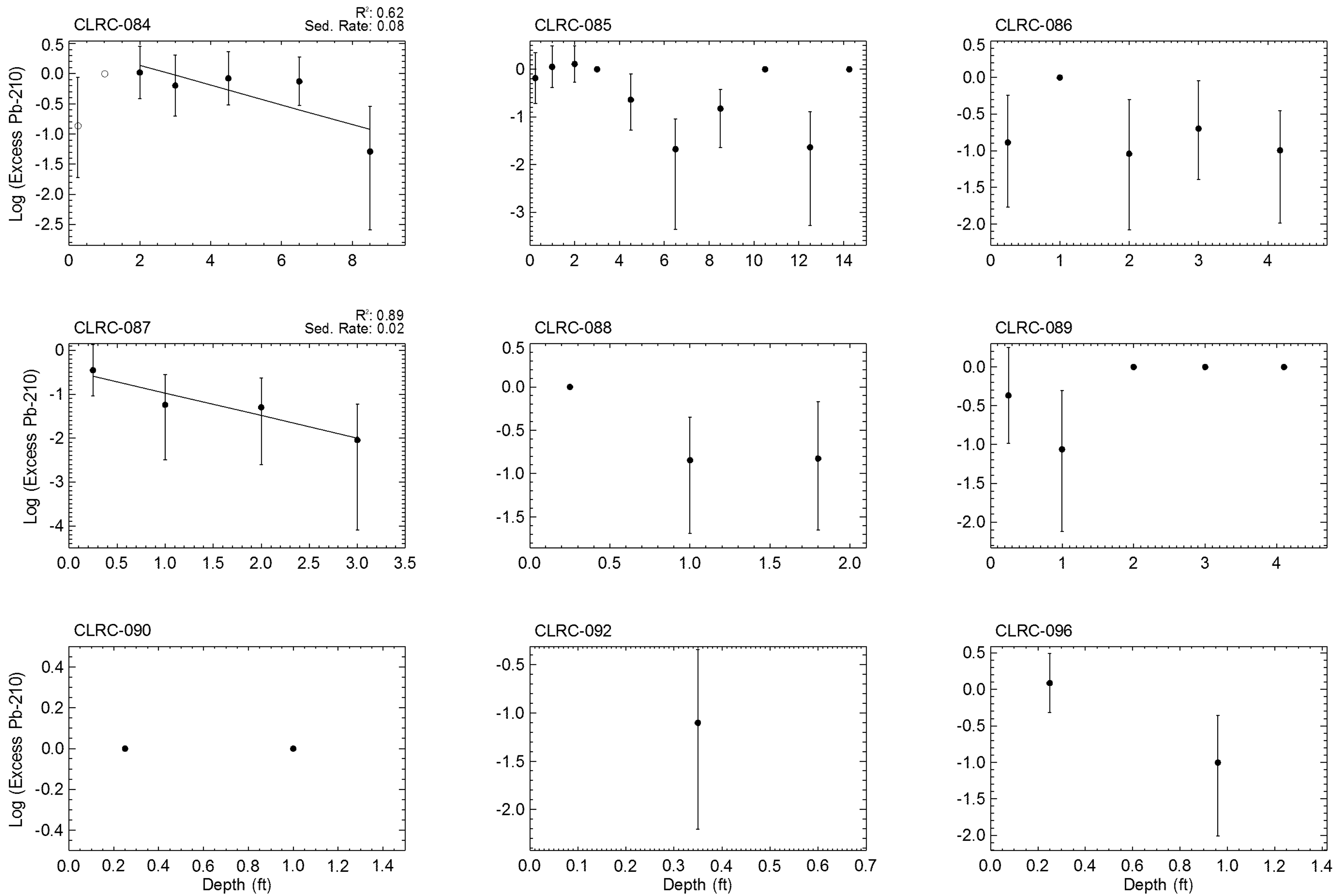

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1j

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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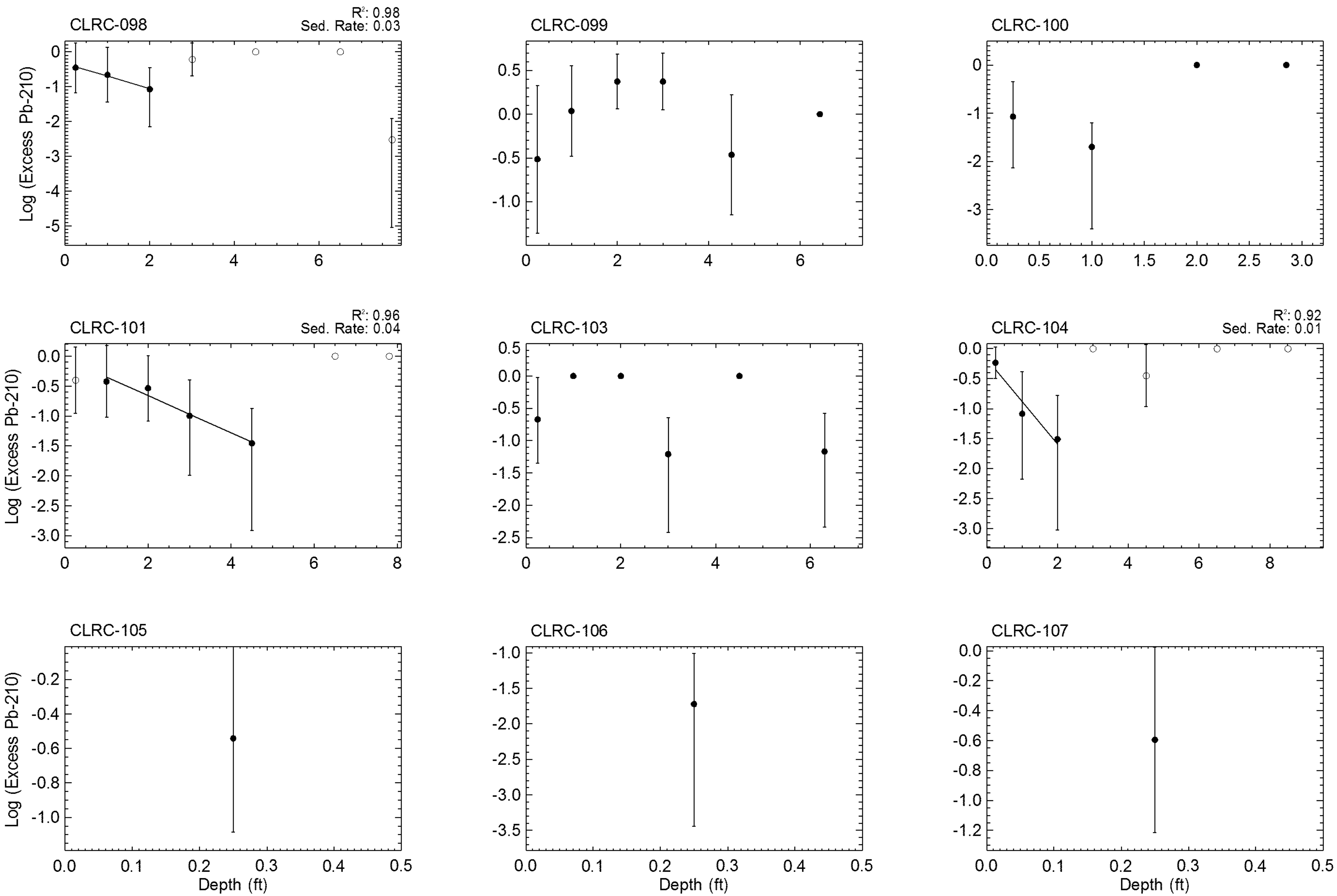

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1k

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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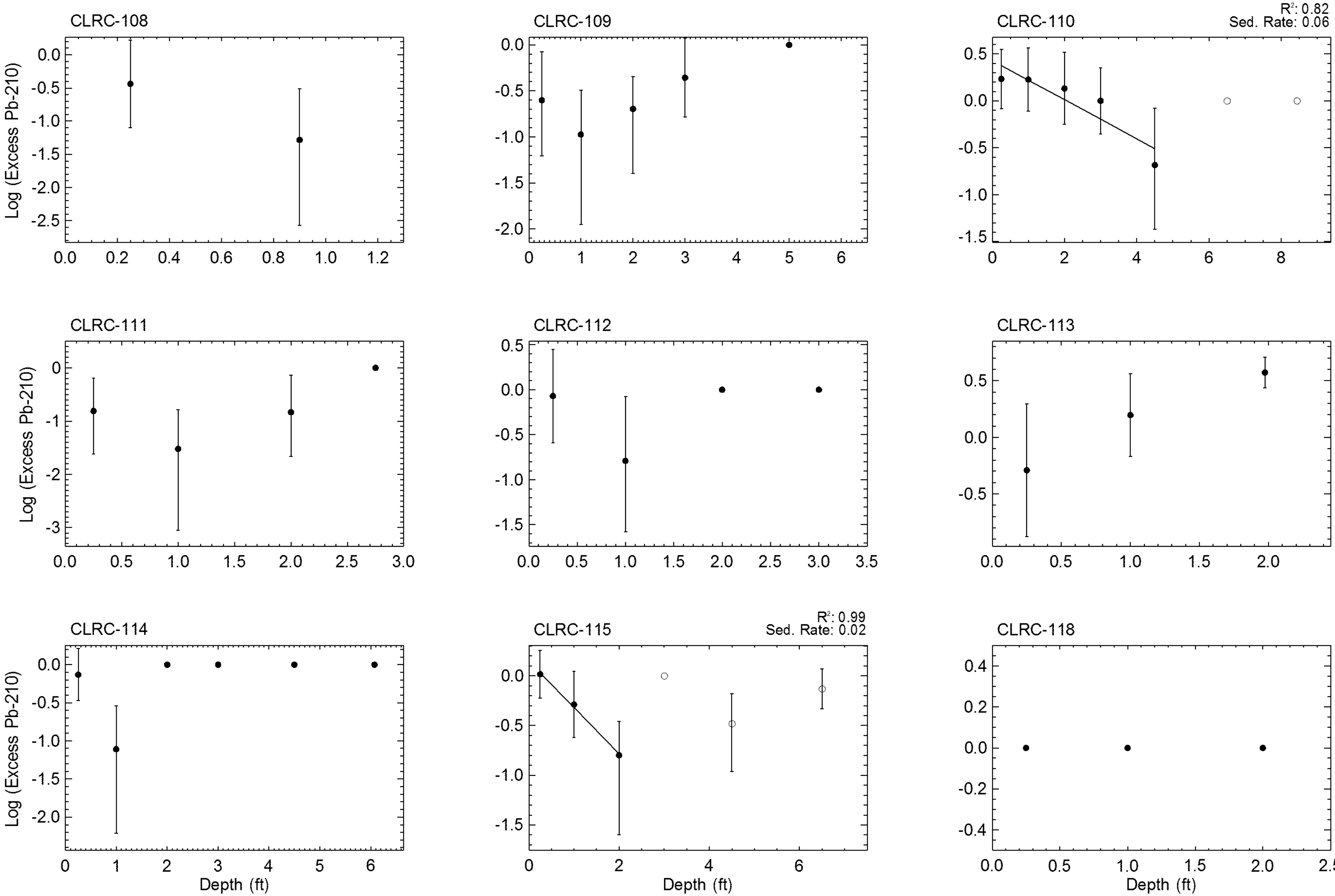

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure A-1l

Pb-210 Depth Profile in 2008 LRC Data
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Sedimentation rate in ft/yr
Open symbols indicate data not used in regression

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APPENDIX A
TABLES

Table A-1
Classification of Cs-137 Sediment Profiles

Classification of Core	Onset (1954)	Peak (1963)	Decrease Near Surface	Summary
A	X	X	X	Well-maintained profile, onset and burial evident. Provides three markers for calculation of three sedimentation rates.
B	--	X	X	Measurable peak, burial evident, but no onset. Only two markers for calculation of one sedimentation rate.
C	X	--	--	May have little/no burial at the surface, but onset evident. One sedimentation rate can be calculated.
D	--	--	--	Cs-137 may or may not be present. If present, no pattern indicative of consistent deposition.

Table A-2

Summary of Net Sedimentation Rates Based on Radiochemistry Data

Location	River Mile	Cs-137 Evaluation: Classification	Cs-137 Evaluation: Classification Notes	Cs-137 Evaluation: 1963 to 2008 rate (feet/year)	Cs-137 Evaluation: 1954 to 2008 rate (feet/year)	Cs-137 Evaluation: 1954 to 1963 rate (feet/year)	Lead-210 Evaluation: Net rate (feet/year)	Lead-210 Evaluation: Correlation Coefficient	Lead-210 Evaluation: Notes	Rate for Depictions	Selected Rate Calculation
2008 CLRC-001	-0.15	D	No onset, no peak	-	-	-	0.55	0.91	-	0.55	Lead-210 rate (feet/year)
2008 CLRC-002	0	D	All non-detect	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-003	0.22	D	One detect at surface	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-004	-0.03	D	No onset, no peak	-	-	-	0.25	0.85	Removed upper point	0.25	Lead-210 rate (feet/year)
2008 CLRC-005	0.15	D	No onset, no peak	-	-	-	0.14	0.93	Removed upper point	0.14	Lead-210 rate (feet/year)
2008 CLRC-006	0.35	A		0.02	0.06	0.22	0.05	0.92	Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-007	0.41	A		0.02	0.04	0.11	0.11	0.84	Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-008	0.37	D	No onset, no peak	-	-	-	0.14	0.73	Removed upper two points	0.14	Lead-210 rate (feet/year)
2008 CLRC-009	0.46	D	No onset, no peak	-	-	-	0.20	0.86	-	0.20	Lead-210 rate (feet/year)
2008 CLRC-010	0.63	D	No onset, no peak	-	-	-	0.27	0.83	Removed upper two points, two rates calculated (most recent rate reported)	0.27	Lead-210 rate (feet/year)
2008 CLRC-011	0.54	D	One detect at surface	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-012	0.66	D	No onset, no peak	-	-	-	0.12	0.93	Rate based on partial dataset	0.12	Lead-210 rate (feet/year)
2008 CLRC-013	0.74	D	No onset, no peak	-	-	-	0.15	0.93	Rate based on partial dataset	0.15	Lead-210 rate (feet/year)
2008 CLRC-014	1.03	A		0.10	0.12	0.22	0.09	0.95	Rate based on partial dataset	0.10	1963 to 2008 rate (feet/year)
2008 CLRC-015	1.11	A		0.07	0.12	0.39	0.06	0.94	Removed upper point, Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-016	1.11	D	No onset, no peak	-	-	-	0.34	0.92	Removed upper point	0.34	Lead-210 rate (feet/year)
2008 CLRC-017	1.07	A	Fluctuation near surface	0.23	0.27	0.44	0.07	0.99	Rate based on partial dataset, two rates calculated (most recent rate reported)	0.23	1963 to 2008 rate (feet/year)
2008 CLRC-018	1.47	A		0.07	0.08	0.17	0.03	0.98	Removed upper point, Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-019	1.47	D	No onset, no peak	-	-	-	0.04	0.99	Rate based on partial dataset	0.04	Lead-210 rate (feet/year)
2008 CLRC-020	1.47	A		0.10	0.12	0.22	0.09	0.91	Rate based on partial dataset	0.10	1963 to 2008 rate (feet/year)
2008 CLRC-021	1.94	A		0.07	0.12	0.39	0.04	0.90	Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-022	2.64	A		0.04	0.06	0.11	0.03	0.97	Rate based on partial dataset	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-023	2.62	A		0.14	0.19	0.44	0.07	0.99	Rate based on partial dataset	0.14	1963 to 2008 rate (feet/year)
2008 CLRC-024	2.62	A	Secondary peak	0.04	0.08	0.28	-	-	No consistent decline	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-025	2.85	A		0.10	0.12	0.22	-	-	No consistent decline	0.10	1963 to 2008 rate (feet/year)

Table A-2

Summary of Net Sedimentation Rates Based on Radiochemistry Data

Location	River Mile	Cs-137 Evaluation: Classification	Classification Notes	1963 to 2008 rate (feet/year)	1954 to 2008 rate (feet/year)	1954 to 1963 rate (feet/year)	Lead-210 Evaluation: Net rate (feet/year)	Correlation Coefficient	Notes	Rate for Depictions	Selected Rate Calculation
2008 CLRC-026	3.17	A		0.02	0.04	0.12	0.02	1.00	Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-027	3.52	B	No onset, fluctuation near surface	0.23	-	-	0.10	0.94	Removed upper 2 points, rate calculated with partial data set	0.23	1963 to 2008 rate (feet/year)
2008 CLRC-028	3.53	A		0.14	0.12	0.00	0.08	0.93	-	0.14	1963 to 2008 rate (feet/year)
2008 CLRC-029	3.53	A		0.02	0.06	0.22	-	-	No consistent decline	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-030	4.25	A		0.07	0.08	0.17	0.01	0.93	Removed upper point, Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-031	4.25	A	Fluctuation near surface	0.07	0.06	0.00	0.03	0.99	Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-032	4.25	A		0.10	0.12	0.22	0.16	0.81	Removed upper point, Rate based on partial dataset	0.10	1963 to 2008 rate (feet/year)
2008 CLRC-033	5	B	No onset, fluctuation near surface	0.07	-	-	0.08	0.74	-	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-034	5.3	D	No onset, no peak	-	-	-	0.07	0.95	-	0.07	Lead-210 rate (feet/year)
2008 CLRC-035	5.51	D	One detect at surface	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-036	5.51	B	No onset	0.14	-	-	0.10	0.66	-	0.14	1963 to 2008 rate (feet/year)
2008 CLRC-037	5.51	B	No onset , secondary peak	0.07	-	-	0.02	1.00	Removed upper point, Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-038	6	A		0.07	0.12	0.39	0.04	0.90	Removed upper point, Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-039	6.27	A	Fluctuation near surface	0.10	0.12	0.22	0.05	0.97	Rate based on partial dataset	0.10	1963 to 2008 rate (feet/year)
2008 CLRC-040	6.49	A		0.02	0.06	0.22	-	-	No consistent decline	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-041	6.49	B	No onset, fluctuation near surface	0.07	-	-	0.02	0.83	Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-042	6.5	D	No onset, no peak	-	-	-	0.04	0.97	-	0.04	Lead-210 rate (feet/year)
2008 CLRC-043	7	B	No onset	0.04	-	-	-	-	No consistent decline	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-044	7	C	No decline towards surface	-	0.04	-	0.02	1.00	Rate based on partial dataset	0.04	1954 to 2008 rate (feet/year)
2008 CLRC-045	7	A	Marginal surficial decline	0.02	0.04	0.11	-	-	No consiste nt decline	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-046	7.45	D	One detect at surface	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-047	7.45	C	No decline towards surface	-	0.04	-	-	-	No consistent decline	0.04	1954 to 2008 rate (feet/year)

Table A-2

Summary of Net Sedimentation Rates Based on Radiochemistry Data

		Cs-137 Evaluation					Lead-210 Evaluation				
Location	River Mile	Classification	Classification Notes	1963 to 2008 rate (feet/year)	1954 to 2008 rate (feet/year)	1954 to 1963 rate (feet/year)	Net rate (feet/year)	Correlation Coefficient	Notes	Rate for Depictions	Selected Rate Calculation
2008 CLRC-048	7.44	D	Low activity	-	-	-	0.02	0.92	Rate based on partial dataset	0.02	Lead-210 rate (feet/year)
2008 CLRC-049	7.86	D	No onset, no peak	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-050	7.97	A		0.02	0.04	0.11	0.03	0.68	-	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-051	7.97	D	No onset, no peak, low activity	-	-	-	0.01	0.96	-	0.01	Lead-210 rate (feet/year)
2008 CLRC-052	7.97	D	One detect at surface	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-054	8.44	D	All non-detect	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-055	8.44	C	No decline towards surface	-	0.02	-	-	-	No consistent decline	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-056	8.98	B	No onset, fluctuation near surface	0.14	-	-	0.20	0.86	Removed upper four points, Rate based on partial dataset	0.14	1963 to 2008 rate (feet/year)
2008 CLRC-057	8.99	A		0.02	0.08	0.39	0.03	0.88	Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-058	9.42	A	Marginal surficial decline	0.02	0.08	0.39	0.02	1.00	Removed upper point, Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-059	9.5	D	No data	-	-	-	-	-	No data		No rate calculated
2008 CLRC-060	9.57	A		0.07	0.08	0.17	0.04	0.66	Rate based on partial dataset, coarser material in bottom segments included in calculation	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-061	10.03	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-062	10.02	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-063	10.27	A		0.02	0.04	0.12	0.09	0.59	-	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-064	10.55	C	No decline towards surface	-	0.02	-	-	-	No consistent decline	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-065	10.55	C	No decline towards surface	-	0.02	-	-	-	No consistent decline	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-066	10.93	D	Low activity	-	-	-	-	-	Only two data points		No rate calculated
2008 CLRC-067	10.93	A		0.02	0.04	0.11	-	-	No consistent decline	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-068	11.32	C	No decline towards surface	-	0.04	-	-	-	No consistent decline	0.04	1954 to 2008 rate (feet/year)
2008 CLRC-069	11.51	C	No decline towards surface	-	0.02	-	0.03	0.87	Rate based on partial dataset	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-070	11.51	D	No onset, no peak	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-071	11.98	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-072	12.03	D	One detect at surface	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-073	12.3	B	No onset	0.02			0.05	0.99	-	0.02	1963 to 2008 rate (feet/year)

Table A-2

Summary of Net Sedimentation Rates Based on Radiochemistry Data

		Cs-137 Evaluation					Lead-210 Evaluation				
Location	River Mile	Classification	Classification Notes	1963 to 2008 rate (feet/year)	1954 to 2008 rate (feet/year)	1954 to 1963 rate (feet/year)	Net rate (feet/year)	Correlation Coefficient	Notes	Rate for Depictions	Selected Rate Calculation
2008 CLRC-074	12.56	D	No onset, no peak	-	-	-	0.16	0.71	Oscillating concentrations	0.16	Lead-210 rate (feet/year)
2008 CLRC-075	12.56	D	No onset, no peak, low activity	-	-	-	-	-	Two data points		No rate calculated
2008 CLRC-076	12.79	C	No decline towards surface	-	0.02	-	-	-	No consistent decline	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-077	12.84	A		0.04	0.04	0.00	0.02	0.96	Rate based on partial dataset	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-078	13.23	B	No onset, fluctuation near surface	0.10			0.11	0.91	Removed upper point, rate based on partial dataset	0.10	1963 to 2008 rate (feet/year)
2008 CLRC-079	13.58	D	No onset, no peak	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-080	13.58	D	Low activity	-	-	-	0.03	1.00	Rate based on partial dataset	0.03	Lead-210 rate (feet/year)
2008 CLRC-081	14.09	D	No onset, no peak		-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-082	14.09	B	No onset, fluctuation near surface	0.23	-	-	-	-	No consistent decline	0.23	1963 to 2008 rate (feet/year)
2008 CLRC-083	14.21	D	No onset, no peak	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-084	14.22	B	No onset, secondary peak	0.04	-	-	0.08	0.64	Removed upper two points	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-085	14.81	A		0.04	0.08	0.28	-	-	No consistent decline	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-086	15.07	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-087	15.07	D	Low activity	-	-	-	0.03	0.90	-	0.03	Lead-210 rate (feet/year)
2008 CLRC-088	15.5	D	All non-detect	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-089	15.5	D	Low activity				-	-	No consistent decline		No rate calculated
2008 CLRC-090	15.63	D	All non-detect	-	-	-	-	-	Two data points		No rate calculated
2008 CLRC-092	16	D	One detect at surface	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-096	17.08	D	No onset, no peak, low activity	-	-	-	-	-	Two data points		No rate calculated
2008 CLRC-098	17.46	A		0.02	0.02	0.00	0.04	0.99	Rate based on partial dataset	0.02	1963 to 2008 rate (feet/year)
2008 CLRC-099	17.47	A		0.07	0.08	0.17	-	-	No consistent decline	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-100	17.59	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-101	17.61	C	No decline towards surface	-	0.02	-	0.04	0.97	Removed upper point, Rate based on partial dataset	0.02	1954 to 2008 rate (feet/year)
2008 CLRC-103	17.73	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-104	18.37	D	Low activity	-	-	-	0.02	0.93	Rate based on partial dataset	0.02	Lead-210 rate (feet/year)
2008 CLRC-105	8.03	D	Low activity	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-106	8.03	D	Low activity	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-107	8.03	D	Low activity	-	-	-	-	-	One data point		No rate calculated
2008 CLRC-108	11.21	D	Low activity	-	-	-	-	-	Two data points		No rate calculated

Table A-2

Summary of Net Sedimentation Rates Based on Radiochemistry Data

Location	River Mile	Cs-137 Evaluation					Lead-210 Evaluation			Rate for Depictions	Selected Rate Calculation
		Classification	Classification Notes	1963 to 2008 rate (feet/year)	1954 to 2008 rate (feet/year)	1954 to 1963 rate (feet/year)	Net rate (feet/year)	Correlation Coefficient	Notes		
2008 CLRC-109	11.21	D	All non-detect	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-110	11.21	A		0.04	0.06	0.11	0.06	0.82	Rate based on partial dataset, finer sediments in bottom segment included in rate calculation	0.04	1963 to 2008 rate (feet/year)
2008 CLRC-111	15.55	D	No onset, low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-112	15.55	D	Low activity	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-113	15.55	D	No onset, no peak	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-114	9.6	D	One detect at surface	-	-	-	-	-	No consistent decline		No rate calculated
2008 CLRC-115	4.21	A	Fluctuation near surface	0.07	0.08	0.17	0.03	1.00	Rate based on partial dataset	0.07	1963 to 2008 rate (feet/year)
2008 CLRC-118	14.21	D	One detect at surface	-	-	-	-	-	No consistent decline		No rate calculated

APPENDIX B
OVERVIEW OF THE LPR HISTORICAL 2,3,7,8-TCDD SOURCE AND THE SUPPORT FOR ITS REGIONAL DOMINANCE

B.1 THE 2,3,7,8-TCDD SOURCE

The Lister Avenue Site (Site) is situated along the southern shore of the Lower Passaic River (LPR), approximately 3.1 miles upstream of where the LPR mouth meets Newark Bay (see Figure B-1). Between approximately 1948 and 1969, 2,4,5-trichlorophenol and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were manufactured at the Site in the production of phenoxy herbicides, including the military defoliant Agent Orange (Chaky 2003; Lilienfeld and Gallo 1989). During this period, approximately 7 to 11 million kilograms of 2,4,5-T were produced (Worthington 1983; Silbergeld et al. 1993), representing 4 to 7 percent of the total United States output of 2,4,5-T between 1948 and 1969 (Chaky 2003).

One of the byproducts of the 2,4,5-trichlorophenol manufacturing process is 2,3,7,8-tetrachlorodibenzodioxin (2,3,7,8-TCDD; Kearney et al. 1973; Hay 1982), which has been the subject of much study due to its potential toxicological effects on humans (Lilienfeld and Gallo 1989). Concentrations of up to 40 milligrams per kilogram (mg/kg) have been measured in Agent Orange samples (Trost 1984; Buckingham 1982; Young et al. 1983; NAS 1974). Similar 2,3,7,8-TCDD concentrations were measured in soils from the Site (Belton et al. 1985). The U.S. Environmental Protection Agency (USEPA) added the Site to the Superfund National Priorities List (NPL) in September 1984 because of this 2,3,7,8-TCDD contamination, and the Site underwent several remedial actions under New Jersey Department of Environmental Protection and USEPA oversight between 1984 and 2004 (USEPA 2008; Tierra Solutions Inc. [TSI] 2008). In addition to upland remedial efforts, several studies have been initiated in the Passaic River, Newark Bay, and surrounding environs. A Remedial Investigation (RI)/Feasibility Study (FS) was initiated for the lower 6 miles of the LPR in 1994, and for Newark Bay in 2004, including portions of the Hackensack River, Arthur Kill, and Kill Van Kull. Also in 2004, a joint Superfund-Water Resources Development Act study of the entire LPR was initiated. In 2008, Occidental Chemical Corporation and TSI agreed to remove approximately 200,000 cubic yards (cy) of the most highly dioxin-contaminated sediments from the LPR in the immediate vicinity of the Site (see Figure B-2), including a Phase I removal area along the Site's shoreline (approximately 40,000 cy) and an adjacent Phase II removal area (approximately 160,000 cy). Sediment cores collected in 2009 and 2011 from within the Phase I removal footprint detected 2,3,7,8-

TCDD concentrations as high as 35 mg/kg, and dredging of this area was completed in summer 2012.

Several investigators have concluded that the Site was the dominant 2,3,7,8-TCDD source to the LPR and its environs. Bopp et al. (1991) reached this conclusion (also for 2,3,7,8-tetrachlorodibenzofuran [2,3,7,8-TCDF] and dichlorodiphenyltric hloroethane [DDT]) on the basis of age-dated sediment cores collected near the Site and in the surrounding region, noting in particular that: 1) the timing of peak concentration coincides with the production period at the Site; 2) concentrations decline moving away from the Site for time horizons in the 1960s and 1980s (also in Bopp et al. 1998); 3) the decline between the 1960s and 1980s is consistent with the Site production ceasing in 1969; and 4) high concentrations were found in soil samples collected from the Site. Similar regional spatial and temporal patterns were noted by Chaky (2003) for the 1960s and 1995 periods using age-dated cores from Newark Bay and throughout the New York (NY)/New Jersey (NJ) Harbor Estuary. Chaky (2003) further noted a similar spatial pattern in the ratio of 2,3,7,8-TCDD to total TCDD, a "fingerprint" suggested by Tong et al. (1990) and Bopp (1992), which is known to be characteristically high for waste associated with the 2,4,5-T manufacturing process used at the Site. Soil samples collected in the vicinity of the Site exhibited ratios in the range of 0.86 to 0.98 (Umbreit et al. 1986; Wenning et al. 1993a), and LPR sediments show only slightly lower values (Chaky [2003] measured 0.71 and 0.86 in Newark Bay, and more recent LPR data generally indicate a ratio above 0.6 [discussed below]). By contrast, wastewater and atmospheric sources exhibit a much lower ratio on the order of 0.06 or less (Chaky 2003). Chaky (2003) concluded that the ratio of 2,3,7,8-TCDD to total TCDD can be considered a fingerprint, which distinguishes polychlorinated dibenzodioxin (PCDD) and polychlorinated dibenzofuran (PCDF) contamination originating from the Site from the major background or non-point sources to the LPR. Using data from the 1990s, Hansen (2002) concluded via a Principal Component Analysis (PCA) and Cluster Analysis that the Site was the most dominant single source of 2,3,7,8-TCDD to the NY/NJ Harbor Estuary. Most recently, the dominant source hypothesis formed the basis for the work of Chant et al. (2010), based on the consistency in timing between peak Site production and the 2,3,7,8-TCDD peak concentration observed in five high resolution cores spaced along the LPR from river mile (RM) 1.4 up to RM 12.6. Chant et al. (2010) concludes that the upstream (landward) sediment transport mechanisms that dominate during low flow conditions explain Site contamination reaching RM 12.6, especially given two conditions that would have favored enhanced upstream transport at the time of peak discharges. First, upstream salt front penetration during low flows would have been greater before widespread infilling of the navigation channel occurred. Second, Site peak production years coincided with a drought period from 1962 to 1966, during which low flow conditions and upstream transport would have been more common.

The dominance of the Site source was challenged[1] by a series of papers analyzing datasets from the 1990s with statistical pattern recognition techniques (e.g., PCA, Polytropic Vector Analysis, and Cluster Analysis) attempting to demonstrate that a multitude of sources contributed to the various PCDD/PCDF congeners in the LPR, Newark Bay, and surrounding areas. The authors hypothesized that these sources likely included industrial discharges, municipal sewage and wastewater, waste incineration, combustion engines, coal-fired power plants and sources associated with polychlorinated biphenyls (PCBs), and combined sewer overflows (Wenning et al. 1992, 1993a, 1993b; Ehrlich et al. 1994; Huntley et al. 1997, 1998). Wenning et al. (1993a) further indicates that the PCDD/PCDF distribution in soils on the Site and sediments adjacent to the Site are dissimilar to sediments elsewhere in the estuary. However, these findings do not conflict with the hypothesis of a dominant 2,3,7,8-TCDD source because 2,3,7,8-TCDD is generally a small percentage of the overall PCDD/PCDF mass (Bopp et al. 1991; Hansen 2002). For example, Bopp et al. (1991) notes that octachlorodibenzodioxin (OCDD) is by far the more abundant dioxin in Newark Bay and Bopp et al. (1998) suggests an atmospheric signal based on regional patterns. Rather, what distinguishes the Site source is the dominance of 2,3,7,8-TCDD to the total TCDD concentration, and hence the characteristic fingerprint used by Chaky (2003).

Lastly, it is noted that two studies (Huntley et al. 1998; Hansen 2002) suggested that 2,3,7,8-TCDD was contributed from a source located approximately 11 miles upstream of the LPR mouth on the Third River. However, this presumption is based on a single sample point having congener concentrations an order of magnitude lower than the downstream sediments, and provides no indication of a substantive impact on the 2,3,7,8-TCDD concentrations in the river. Moreover, as discussed below in the context of larger and more

[1] In addition, the conclusions of Bopp et al. (1991) were debated in follow-up comments by Bedbury (1992), Wenning et al. (1992), and Bopp (1992).

recent datasets, 2,3,7,8-TCDD concentrations at or above this section of the river are consistent with the Site source signature as well as upstream tidal transport processes.

B.2 2,3,7,8-TCDD AS A TRACER OF OPPORTUNITY

The longitudinal distribution of core-maximum, organic carbon (OC)-normalized 2,3,7,8-TCDD concentrations in LPR and Newark Bay cores and the corresponding estimated mass inventory are shown on Figure B-3. Spatial patterns in sediment concentration data are often used to identify contaminant sources to a system because the highest concentrations typically occur at the source location and decline with distance from the source. This approach was used by Bopp et al. (1991, 1998) and Chaky (2003) to originally suggest that the Site was the regional source of 2,3,7,8-TCDD to the Newark Bay complex, based on concentrations associated with specific time horizons as identified by geochronological markers. Another prominent example is provided by Connolly and Glaser (2002) in the Southern California Bight, where an ocean outfall was identified as the dominant source of regional dichlorodiphenyldichloroethylene (DDE) contamination based on observations of monotonically declining concentrations moving away from the outfall. The same approach is used here, but interpretations are adjusted to account for the damping effect of estuarine sediment redistribution processes on the source signal within the LPR.

The longitudinal distribution of average core-maximum 2,3,7,8-TCDD concentration in the LPR and Newark Bay cores (see Figure B-3 top panel; note the OC normalization) indicate that 2,3,7,8-TCDD levels are highest in the region encompassing the Site (RM 2 to RM 4), particularly within the Phase I removal footprint immediately adjacent to the Site where the average peak concentration (red point) is more than 100 times greater than in the remaining areas in the RM 2 to RM 4 bin. The average peak concentrations are fairly well distributed across the 2-mile bins throughout the lower 14 miles of the river (all are within a factor of 5 of the RM 2 to RM 4 bin), with a decline moving away from the RM 2 to RM 4 bin. Moving across Newark Bay, the concentrations drop dramatically; the average peak concentration in Lower Newark Bay is approximately 100 times lower than the average within the RM 2 to RM 4 reach and approximately 10,000 times lower than in the Phase I removal footprint. Likewise, moving upstream of RM 14, peak concentrations drop on average by approximately 2 orders of magnitude relative to LPR levels, reaching levels similar to those above Dundee

Dam. Although the local source signal of this metric within the lower 12 to 14 miles of the LPR is damped (presumably by estuarine transport processes, discussed below), the larger scale pattern is consistent with the Site being the dominant source of the historical 2,3,7,8-TCDD contamination in the region; 2,3,7,8-TCDD levels from sources upstream of Dundee Dam and LPR tributaries (see Figure B-3 top panel) are too low to account for the 2,3,7,8-TCDD contamination observed throughout the LPR.

Within the lower LPR, the strength of the source is more clearly illustrated by the longitudinal distribution of estimated 2,3,7,8-TCDD mass inventory on Figure B-3 (bottom panel), which applies a Thiessen polygon approach to a somewhat modified version of the core dataset[2]. The mass inventory estimate for the RM 2 to RM 4 bin is highest, declining upstream and downstream. Although the distribution is influenced by the long-term trapping behavior of the estuary, it supports the hypothesis that the Site loading dominates all other sources of 2,3,7,8-TCDD to the LPR and Newark Bay.

Further support for the dominance of the 2,3,7,8-TCDD source is provided by the spatial distribution of 2,3,7,8-TCDD to total TCDD ratios at the depth of maximum 2,3,7,8-TCDD concentration (see Figure B-4, top panel), and we note that age dating of sediment cores collected immediately adjacent to the Site in January 2011 further supports the use of this fingerprint (see Figure B-5[3]). Peak ratios of 0.6 or greater are almost universal in the LPR

[2] Mass per area (MPA) values are computed from cores as the product of paired dry density and 2,3,7,8-TCDD concentrations, summed over the length of the sediment column, using an average dry density when core-specific values were unavailable. Only "complete cores" with continuous 2,3,7,8-TCDD profiles are analyzed in this fashion, with the exception of high resolution cores where linear interpolation between measured values was performed. Estimates of 2,3,7,8-TCDD mass inventory are generated using Thiessen polygons around the calculated MPA values. The interpolated dataset differs somewhat from the one used in the top panel of Figure B-3, in that the 1995 core dataset is also included to better constrain mass estimates. This same change was not made to the top panel of Figure B-3 in order to maintain consistency with other concentration figures in this report; conclusions regarding the trends in mean peak 2,3,7,8-TCDD concentration are not strongly influenced by this choice.

[3] It should be noted that in the bottom half (i.e., below the estimated 1954 time horizon) of Core HRC-02H there are several instances where 2,3,7,8-TCDD concentrations are elevated but the ratio of 2,3,7,8-TCDD to Total TCDD is less than 0.6. Although the reason(s) for the lower ratios in this portion of the core is not known, PCDD/F congener results for some intervals in this portion of the core were estimated by the laboratory due to matrix interferences from the very high concentrations of target PCDD/F congeners in these samples. Additional analysis of the Site fingerprint is ongoing and will be incorporated in future updates to this document.

below RM 14, with most samples falling between 0.7 and 1.0. This ratio range is consistent with the Site source (based on Site data reported by Umbreit et al. [1986] and Wenning et al. [1993a]), and the upstream extent of the high ratios is consistent with estuarine transport of material originating at the Site (see Section 5). Moving through Newark Bay, lower ratios become more common, suggesting dilution from dioxin sources with a much lower 2,3,7,8-TCDD fraction of total TCDD. Likewise, above approximately RM 14, ratios decline toward background levels (as discussed previously, 0.06 or less per Chaky [2003]), consistent with the accompanying drop in concentration. Moreover, it is noted that 2,3,7,8-TCDD peak concentrations above approximately 100 ng/kg and 1,000 ng/kg are almost exclusively associated with 2,3,7,8-TCDD to total TCDD ratios in excess of about 0.6 and 0.7, respectively (see Figure B-4, bottom panel). Thus, elevated concentrations throughout the system are associated with the fingerprint ratio that has been attributed to the Site. Although it is acknowledged that the 2,3,7,8-TCDD to total TCDD ratio patterns do not preclude the influence of other 2,3,7,8-TCDD sources with a similar signature, when combined with the peak concentration and estimated mass inventory spatial patterns, the weight of evidence strongly indicates that the Site is the dominant source of 2,3,7,8-TCDD contamination throughout the LPR and Newark Bay.

Note: An additional figure showing peak Passaic River 2,3,7,8-TCDD concentrations in log scale (see Figure B-6) is included in this appendix. This figure demonstrates variability in concentrations over space, and is cited in Section 5 of the main report.

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APPENDIX B
FIGURES

PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure B-1
Lower Passaic River Study Area and Location of the Lister Ave Facility
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

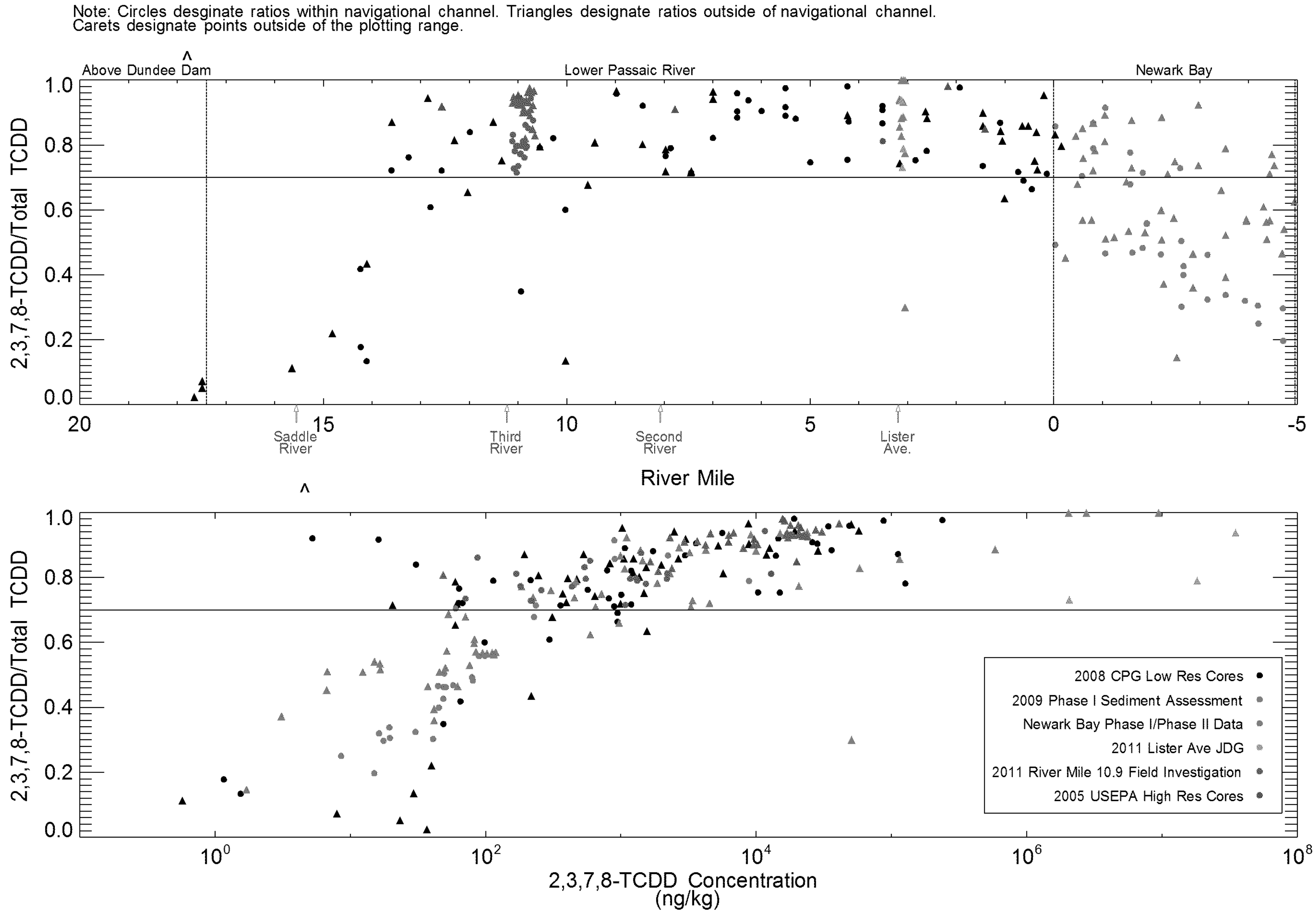
Figure B-2

Near-field Distribution of Estimated 2,3,7,8-TCDD Mass per Area (MPA)

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Inset shows a close-up of the Phase 1 removal footprint adjacent to the Lister Avenue site.



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

Figure B-4

Top Panel: Spatial Trend in 2,3,7,8 TCDD to total TCDD Ratio at the Local Depth of Maximum 2,3,7,8 TCDD Concentration
Bottom Panel: 2,3,7,8 TCDD to total TCDD Ratio as a Function of Maximum 2,3,7,8 TCDD Concentration at the Local Depth

Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

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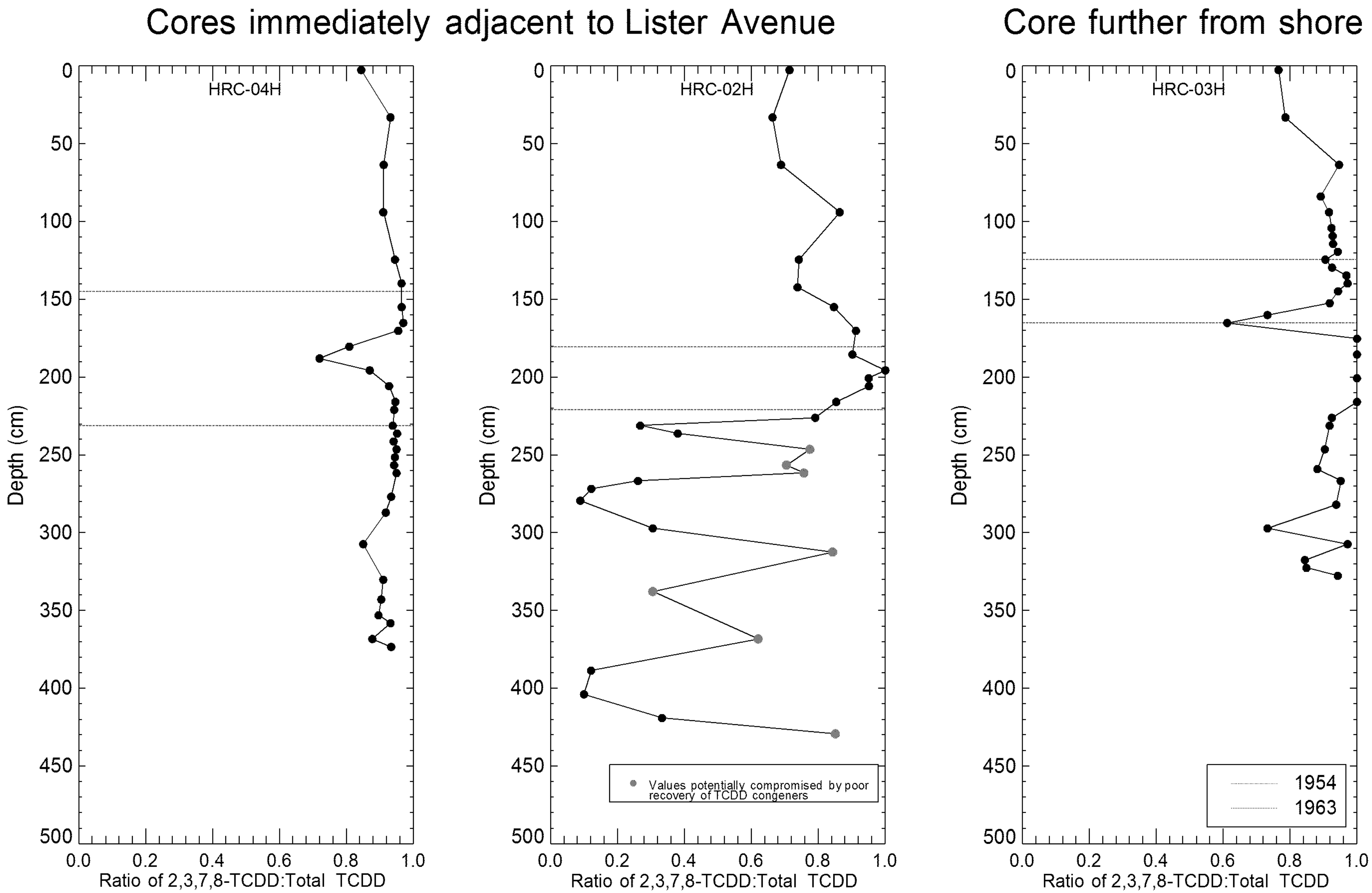


PRELIMINARY DRAFT - FOR DISCUSSION ONLY

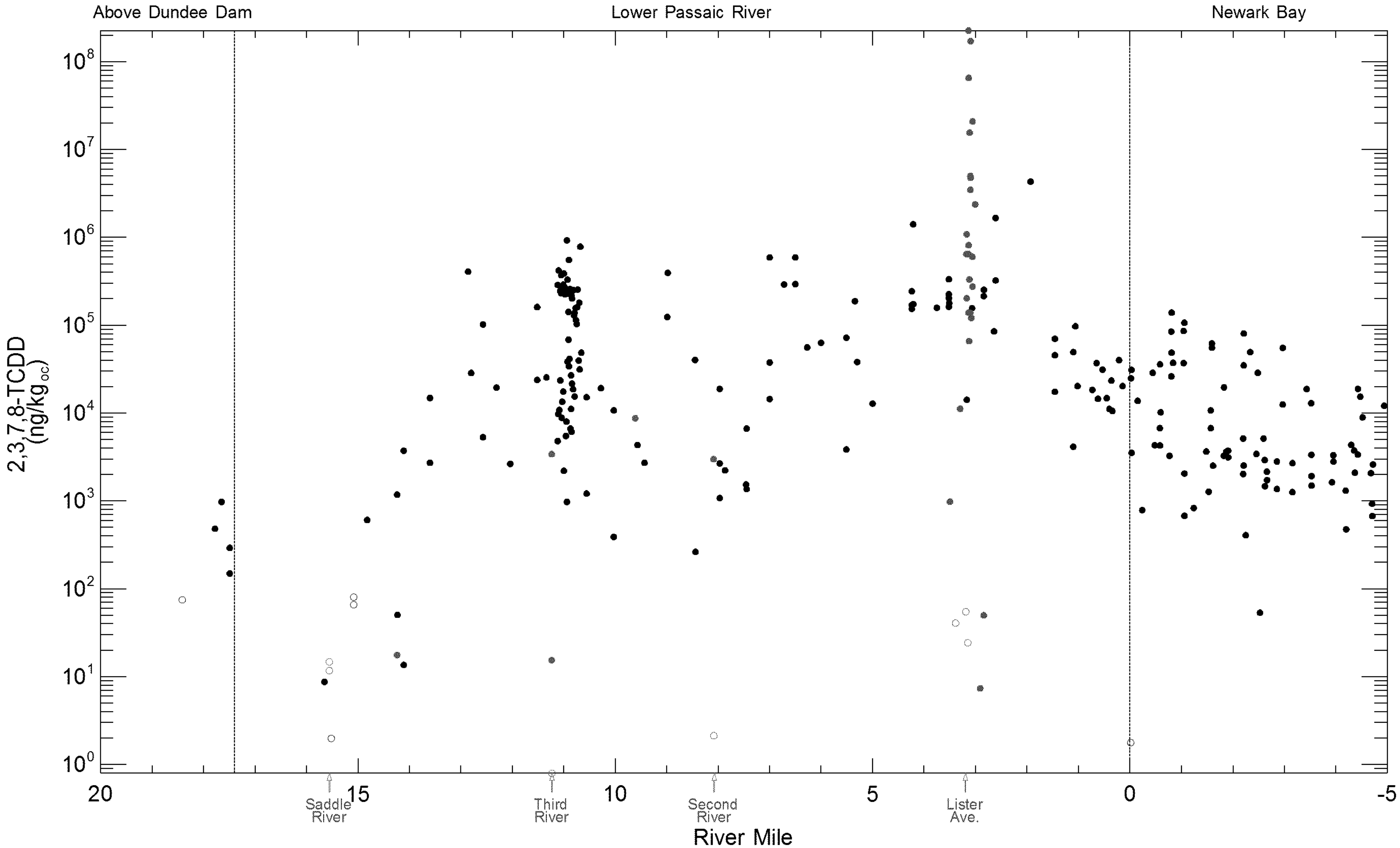
Figure B-5

Vertical Profiles of 2,3,7,8-TCDD:Total TCDD for 2011 High Resolution Cores Collected Near the Lister Avenue Site

Interim Conceptual Site Model

Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Estimated Cs-137 horizons are also shown



PRELIMINARY DRAFT - FOR DISCUSSION ONLY

- Passaic R. / Newark Bay Data
- LPR Tributary Data
- Phase 1 Footprint Data

Figure B-6

Peak 2,3,7,8-TCDD Concentrations in Sediments of the LPR and Newark Bay
Interim Conceptual Site Model
Lower Passaic River Study Area Remedial Investigation/Feasibility Study

Plots include only post 2000 data (listed in Table 3-1). ND OC values excluded
Peak based on dry-weight concentrations

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